BRITISH STANDARD

BS 5489 :
Part 7 : 1992

Incorporating Amendment No. 1

Road lighting

Part 7. Code of practice for the lighting of tunnels and underpasses

BSi

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Electrical Illumination Standards Policy Committee (LGL/-) to Technical Committee LGL/23, upon which the following bodies were represented:

Automobile Association
British Lighting Association for the Preparation of Standards (Britlaps)
British Precast Concrete Federation Ltd.
Chartered Institution of Building Services Engineers
Council for the Protection of Rural England
County Surveyors' Society
Department of Transport
Institution of Civil Engineering Surveyors
Institution of Civil Engineers
Institution of Electrical Engineers
Institution of Lighting Engineers
Institution of Mechanical Engineers
Lighting Industry Federation Ltd.
Royal Fine Art Commission
Scottish Office (Building Directorate)

This British Standard, having been prepared under the direction of the Electrical Illumination Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 August 1992

First published as CP 1004
February 1971
Second edition as BS 5489 :
Part 7 October 1990
Third edition August 1992

The following BSI references relate to the work on this standard:
Committee reference LGL/23
Draft announced in *BSI News*
March 1992
ISBN 0 580 20900 8

Amendments issued since publication

Amd. No.	Date	
9013	May 1996	Indicated by a sideline in the margin S·King Fancul-ti

Summary of pages

The following table identifies the current issue of each page. Issue 1 indicates that a page has been introduced for the first time by amendment. Subsequent issue numbers indicate an updated page. Vertical sidelining on replacement pages indicates the most recent changes (amendment, addition, deletion).

Page	Issue	Page	Issue
Front cover	2	18	original
Inside front cover	2	19	original
a	1	20	2
b	blank	21	original
1	original	22	original
2	original	23	original
3	original	24	original
4	original	25	original
5	original	26	original
6	original	27	original
7	original	28	original
8	original	29	original
9	original	30	original
10	original	31	original
11	original	32	2
12	original	33	original
13	original	34	original
14	original	35	original
15	original	36	original
16	original	Inside back cover	original
17	original	Back cover	2

Contents

Page

Figures

Foreword

This Part of BS 5489 has been prepared under the direction of the Electrical Illumination Standards Policy Committee and is a new edition of BS 5489 : Part 7 : 1990 which is withdrawn.

In recent years there has been an increase in the number of road tunnels in the United Kingdom and a marked growth in demand for underpasses.

In the 1990 edition emphasis was placed upon dealing with the longer tunnel which, because drivers have time to adapt to lower lighting levels, was divided into a number of lighting zones. Procedures for dealing with the different zones were detailed so that, overall, traffic can flow smoothly and safely with little discomfort to drivers.

The procedures can be adapted for shorter tunnels, underpasses and bridged roads and relate to all types of road, including motorways. Daytime recommendations for lighting were covered as well as those for night time and under adverse weather conditions.

This new edition introduces a revised definition of maintenance factor, and incorporates editorial improvements but it does not reflect a full review or revision of the standard, which will be undertaken in due course.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Code of practice

1 Scope

This Part of BS 5489 gives recommendations for the lighting of tunnels including underpasses and relates to all types of road including motorways.

Recommendations are given firstly for the lighting of longer tunnels and secondly, in clause **15**, for the lighting of shorter tunnels and bridged roads, where variations from the basic recommendations become applicable. Tunnel lighting recommendations for daytime and after dark are given for all types of road together with the situations in which artificial lighting in daytime may be unnecessary. Attention is drawn to the importance of adhering to the maintenance schedule to ensure that the design lighting levels are always realized.

This Part of BS 5489 does not deal with subways reserved for pedestrians or cyclists, underground shopping areas, railway station taxi ranks, etc., or with traffic signs, signals and illuminated bollards.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 5489 the definitions given in BS 5225 : Part 1, BS 5489 : Part 1 and BS 6100 : Subsection 2.4.1 apply, together with the following.

NOTE. See also table 1.

2.1 access zone

The length of approach road before a tunnel entrance.

NOTE. Daylight screens, if present, are taken to be part of the tunnel.

2.2 access zone luminance (L_{20})

The average value of the luminance over a 20° diameter circular field of view seen by the driver from the access zone and centred on the tunnel entrance.

NOTE. The particular value of L_{20} at the stopping point SP is termed L_{20}(SP) and that at the adaptation point is termed L_{20}(A).

2.3 adaptation point (A)

That point on the road where as a result of the presence of the relatively dark tunnel entrance which forms a rapidly increasing part of the field of view, the adaptation level of the driver's eyes begins to decrease significantly.

2.4 exit zone

A stretch at the end of a tunnel where the vision of a driver approaching the exit is influenced by the brightness outside the tunnel.

2.5 interior zone

The main stretch of the tunnel, over which the lowest (basic) level of daytime lighting applies.

2.6 interior zone luminance (L_{in})

The average[1] luminance in the interior zone which constitutes the background field against which objects will be visible to drivers.

NOTE. This luminance is sometimes referred to as the basic daytime level when, at the appropriate stage, it extends throughout the tunnel.

2.7 stopping point (SP)

The position within the access zone on the approach road at a distance equal to the stopping sight distance from the tunnel entrance.

2.8 stopping sight distance (SSD)

The theoretical forward sight distance required by a driver, at a given speed, in order to stop when faced with an unexpected hazard on the carriageway.

NOTE. This distance takes account of perception and reaction time and braking distance.

2.9 threshold zone

The first stretch of the tunnel and that which constitutes the bright background against which objects are seen by drivers in the access zone between the SP and the tunnel entrance.

2.10 threshold zone luminance (L_{th})

The average[1] luminance in the threshold zone which constitutes the background field against which objects will be visible to drivers in the access zone between the SP and the tunnel entrance.

NOTE. The particular value of L_{th} at the inner end B of the threshold zone where the transition zone commences is termed L_{th}(B).

2.11 transition zone

Succeeding stretch of the tunnel, after the threshold zone, with a luminance less than that in the threshold zone and designed to maintain an adequate visibility for drivers whilst they progress from the threshold zone to the interior zone.

2.12 transition zone luminance (L_{tr})

The average[1] luminance in the transition zone which constitutes the background field against which objects will be visible to drivers.

2.13 tunnel entrance, mouth or portal

The point at which the covered section of the road commences. This includes any covering which admits daylight, i.e. daylight screens (see **2.1**).

2.14 adaptation

The process by which the properties of the visual system are modified according to the luminances or the colour stimuli presented to it.

---

[1] For the purposes of calculation the average is usually taken to be the average luminance over the road surface. See also clause **16**.

2.15 luminaire

Apparatus which distributes, filters or transforms the lighting given by a lamp or lamps and which includes all the items necessary for fixing and protecting these lamps and for connecting them to the supply circuit.

2.16 flicker

Impression of fluctuating luminance or colour, occurring when the frequency of the variation of the light stimulus lies between a few hertz and the fusion frequency of the images.

2.17 cut-off

Technique used for concealing lamps and surfaces of high luminance from direct view in order to reduce glare.

2.18 reflectance

Ratio of the reflected radiant or luminous flux to the incident flux.

2.19 interreflection

General effect of the reflections of radiation between several reflecting surfaces.

2.20 specular reflection

Reflection without diffusion in accordance with the laws of optical reflection as in a mirror.

2.21 fluorescent lamp

Discharge lamp in which most of the light is emitted by a layer of fluorescent material excited by the ultraviolet radiation from the discharge.

NOTE. This term is most commonly applied to low pressure tubular fluorescent lamps.

2.22 high pressure sodium (vapour) lamp

Sodium vapour lamp in which the partial pressure of the vapour during operation is of the order of 100 mbar[1].

2.23 low pressure sodium (vapour) lamp

Sodium vapour lamp in which the partial pressure of the vapour during operation does not exceed 0.05 mbar.

2.24 louvre

Screen made of translucent or opaque components and geometrically disposed to prevent lamps from being directly visible over a given angle.

2.25 utilization factor

Ratio of the utilized flux to the luminous flux emitted by the lamps.

2.26 translucent plastics

Incompletely diffusing plastics through which objects are not seen distinctly.

2.27 luminance

At a point of a surface and in a given direction, the luminous intensity of an element of the surface, divided by the area of the orthogonal projection of this element on a plane perpendicular to the given direction.

3 General

The object of installing lighting in a road tunnel is to enable traffic to flow through it with the same speed, degree of safety and comfort as on the approach roads.

This aim can be achieved only when road users are sufficiently aware visually of the roadway ahead of them and, in particular, of the presence or absence of other vehicles and possible obstructions. The major difference between tunnel lighting and conventional road lighting is in the need for lighting by day. A driver should be able to see a certain distance ahead such that if an unexpected hazard appears, the driver can react and stop within that distance. When this distance extends into a tunnel there should be a sufficiently high lighting level inside to maintain visibility. If the lighting level is not high enough, the driver will be unable to see into the tunnel, the so-called 'black hole effect'.

During approach and entry to the tunnel, the driver's eyes become adapted to the darker surroundings. This adaptation is a continuous process with the result that further into the tunnel, providing it is of sufficient length, the lighting level may be reduced in stages to a constant level in the tunnel interior. On emerging from a tunnel into daylight, however, the eye adapts far more quickly to the higher luminance level.

Similarly, rearward visibility should be maintained when leaving the tunnel, to facilitate safe manoeuvres immediately beyond the exit zone.

The environmental import of the lighting on its surroundings should not be forgotten. The context can range from open countryside to high density communal areas, or in the case of short tunnels may be related to a building or structure of architectural and historic importance. The effects of the type of lamp chosen, light spillage, fixtures and luminaires should all be considered.

---

[1] 1 mbar = 100 N/m^2 = 100 Pa.

Table 1. Stopping sight distances (SSD) for various design speeds

Design speed (in km/h)	120	100	85	70	60	50
SSD (in m)	215	160	120	90	70	50

NOTE. These values are extracted from Department of Transport Standard TD 9/81 obtainable from DOE/DTP Publication Sales Unit, Building 1, Victoria Road, South Ruislip, Middlesex HA4 0NZ.

4 Basis of design and summary of design procedure

First consideration in a tunnel lighting design is usually given to the determination of the highest access zone luminance occurring at the stopping point, i.e. L_{20}(SP). Methods of doing this are described in clause **5**. From this value, the luminance to be provided in the threshold zone (L_{th}) can be derived as explained in clause **6**.

The level of luminance so determined for the threshold zone of a tunnel is based upon the perception of an object 20 cm square, having a certain contrast. The theoretical background is summarized in appendix A.

The basis for determining the luminances and lengths of each zone can be understood from figure 2. The left hand side of this graph shows how the access zone luminance might vary with distance from the tunnel entrance for a driver approaching the tunnel from the stopping point (SP). The determination of the position of the adaptation point (A) and the way in which its distance from the tunnel entrance affects the length of the threshold zone are explained in **7.1** and **7.2**.

The right hand side of figure 2 represents the luminance necessary in the tunnel where the luminance axis of this plot is the vertical line through the position of the tunnel entrance. The luminance throughout the threshold zone is shown by the full line as being constant, i.e. $L_{th}(B) = L_{th}$. There may be a justification for reducing the threshold zone luminance over the length of the threshold zone. An example of such a reduction is shown in figure 2. See also **7.3**.

Beyond the end of the threshold zone, i.e. past point B, the luminance in the tunnel should be reduced through one or more transition zones to the luminance L_{in} chosen for the interior zone of the tunnel (see clause **9**). The maximum rate at which the luminance can be reduced from $L_{th}(B)$ to L_{in} is given by the appropriate luminance reduction curve in figure 3. The method of fitting the curve to give the transition zone(s) is explained in clause **8**. The experimental derivation of the lighting reduction curves is summarized in appendix A. Lighting for the exit zone is covered in clause **10** and the recommendations for night-time lighting throughout the tunnel are given in clause **12**.

The levels of luminance (in cd/m^2) specified in this standard are maintained values. The surface to which a recommended luminance applies is that of the background against which vehicles and objects will be seen (see **2.6**). Although this background may comprise the road surface, the walls and even the roof, it is the average luminance of the road surface in a zone which should first be determined in ascertaining whether a lighting design meets the recommended luminance value. Subsequently consideration can be given to the lighting of the walls and possibly the roof (see clause **16**).

Uniformity of luminance is considered in clauses **11** and **12**.

The use of illuminance values to specify the lighting in tunnels is not recommended, but an additional computation of illuminance levels and uniformity may be produced for contractual purposes because it is simpler to check illuminance in the completed installation.

5 Determination of the access zone luminance (L_{20})

5.1 It has been found that the value of L_{20} provides adequate quantitative representation of the visual effect of the whole luminance pattern in the driver's field of view. In particular, the highest luminance level L_{th} to be provided in the threshold zone of the tunnel is dependent on the luminance pattern, and hence the maximum value of L_{20}, experienced by the driver at the stopping point (SP) in the access zone, i.e. the maximum value of L_{20}(SP). The position of SP in the access zone is determined by the stopping sight distance (SSD).

The values of SSD to be used in conjunction with this Part of BS 5489 are shown in table 1 as a function of the design speed, i.e. the traffic speed for which the road has been geometrically designed. These values of SSD should be used unless there are circumstances which will result in particularly onerous demands being placed upon drivers' perception as they approach the tunnel. In such cases the SSD relating to the next higher design speed in table 1 should be used. Examples of these circumstances are:

(a) road junctions near or partly within the access or threshold zones of tunnels, giving increased likelihood of lane merging and speed changing;

(b) a mixture of slow and fast vehicles;

(c) limited cross section for emergency situations, e.g. narrow lane width or restricted verge provision.

NOTE. Where such circumstances apply and the design speed is 120 km/h then the SSD should be increased to 295 m. For SSD values corresponding to design speeds not given in table 1, a graph of the relationship between SSD and design speed should be plotted and the appropriate values read off.

It is assumed that the design speed and the operational traffic speed limit of the road system are the same. If they are not, then the tunnel lighting design may be based on the (lower) operational speed limit. However, if this limit were to be subsequently raised, then the lighting in the tunnel would probably be inadequate. It is not recommended that a speed limit be applied specifically to the tunnel section to compensate for lighting which is not up to the necessary standard. Such a procedure will only restrict freely flowing traffic and lead to the very situations which the lighting should be designed to avoid.

Speed of approach affects the value of L_{20}(SP) in that the position of the SP in the access zone will vary; the slower the speed of approach, the nearer the tunnel entrance will the point be and generally the lower the value of L_{20}(SP).

The following methods are recommended for the determination of L_{20} at any point in the access zone, including L_{20}(SP).

(1) ***Direct measurement on site***. This can be carried out at existing tunnels or at the site of a proposed project. Details of the method are given in appendix B. It is generally a rather expensive operation because of the equipment and time involved and should only be used where the tunnel has features difficult to assess by other methods. It is important to obtain the highest value of L_{20}, which is very dependent on sky conditions.

(2) ***Grid method***. This method can be used where (1) is impracticable but photographs or scale drawings of the tunnel approach are available. L_{20} is calculated as an average, weighted according to area, of the individual luminances of each part of the field of view. Typical component luminance values recommended for use are listed in appendix C, together with a worked example. On-site measurements of component luminances (see appendix B) can be used in the calculation to give more representative results.

(3) ***Comparison with existing tunnels***. Considerable experience has been gained in providing satisfactory threshold zone lighting, both in this country and abroad, and it has been found that for a given type of tunnel approach (e.g. in mountains, built-up) a certain range of access zone luminances apply. Diagrams of a number of access zone situations are given in figure 4, together with the range of access zone luminances likely to apply under an illuminance of 100 klx (i.e. maximum summer value). The drawings are made from the distance shown and the 20° field of view is marked. Comparison of the actual tunnel situation with the drawings will yield the range of values of L_{20} which is applicable.

5.2 Methods (1) and (2) of 5.1 give values of L_{20} that are as accurate as can reasonably be obtained as a basis for the lighting design in the tunnel. In the absence of the more precise data that would be provided by these methods, method (3) will give a first approximation of L_{20}(SP) for initial design purposes. It is recommended that method (1) or method (2) of **5.1** is used for determining the final lighting design.

6 Threshold zone lighting during daylight

In order that drivers have adequate visibility into the tunnel, the threshold zone luminance L_{th} should be related to L_{20}(SP) by a factor k as follows: $L_{th} = k\,L_{20}$(SP).

The value of this factor varies with the nature of the road and the traffic: the road lighting categories defined in table 1 of BS 5489 : Part 2 are used as a classification (see table 5 of this standard).

Table 2 gives the recommended values of the threshold zone luminance L_{th} in terms of the factor k by which L_{20}(SP) has to be multiplied.

Table 2. Values of the factor *k*

Speed limit		Road lighting category	Factor *k*
mile/h	km/h		
70 and above	110 and above	Motorways	0.07
50 to 60	80 to 100	Category 2/1 roads and category 2/2 roads when these speed limits are applicable	0.06
30 to 40	50 to 70	Category 2/2 roads when these speed limits apply and category 3/3 roads	0.05

7 Extent of threshold zone

7.1 Determination of length of threshold zone

The length of the threshold zone is related to the position of the adaptation point A and the stopping sight distance (in metres) relevant to the speed of the traffic as follows:

hreshold zone length is either 40 m or (S_{SD} + 20 - *d*) whichever is the greater.

where

S_{SD} is the value of the SSD (in m);

d is the distance (in m) from the adaptation point A to the tunnel entrance.

The derivation of the zone length is shown in figure 2. The additional 20 m on the SSD is to provide the necessary background to reveal an obstacle at the SSD for a driver at the adaptation point. Where the approach speed of the traffic is less than the design speed for the road, e.g. a toll plaza or any road layout which reduces the speed of the traffic on the immediate approach, the length of the threshold zone may be reduced to 40 m.

The contribution to the illumination of the threshold zone by daylight penetrating the entrance is dependent on the structural design and architectural treatment but generally no artificial lighting is necessary in the first 5 m of the tunnel.

7.2 Location of adaptation point (A)

The point A at which the adaptation level of a driver's eyes begins to decrease significantly as the tunnel entrance is approached is an imprecise one. It is, however, important to be able to make an estimation of its position because the greater the distance of point A from the tunnel entrance, the shorter the length of the threshold zone need be, with a consequent saving in cost.

The minimum distance between point A and the tunnel portal can be derived geometrically by considering the point where the top of the tunnel mouth just appears within the 10° angle of elevation of the driver's view (see figure 5). This distance will be about 23 m for a tunnel entrance height of 5.5 m (see table 3).

Table 3. Location of the adaptation point (A)

Height of the top of the tunnel mouth m	Distance (*d*) from the adaptation point (A) to the tunnel entrance (mouth) m
5	20
5.5	23
6	26
6.5	28
7	31
7.5	34
8	37
8.5 and greater	40

The values in table 3 should be used unless a direct determination of the location of A as detailed below shows that its distance from the tunnel mouth differs from the table 3 distance by more than 3 m.

It is possible to assess the distance from A to a particular tunnel entrance directly, by plotting the values of L_{20} as a function of distance between the stopping point (SP) and the tunnel entrance. The values of L_{20} (i.e. average luminance over a 20° field of view centred on the tunnel entrance) may be determined in the manner described in **5.1** (1) or (2) and appendices B and C. The point L_{20}(A) on the resulting curve nearest the tunnel entrance, where L_{20} drops to 90 % of L_{20}(SP), will determine the distance from the tunnel entrance (see figure 2). Where the position of such a drop in L_{20} is uncertain, the formula given on figure 5 should be applied.

7.3 Visibility in threshold zone

The threshold zone is usually designed to have a constant luminance level throughout its length, i.e. L_{th}(B) = L_{th}. However, adequate visibility will be maintained if, after the first 20 m, the threshold zone luminance follows a similar pattern of reduction to that of the adaptation luminance as the driver approaches the tunnel. The access zone luminance values between the stopping point SP and the adaptation point A should be determined directly as described in **5.1**(1) or (2). Then a two or three stepped reduction of the lighting in the threshold zone may be used to realize this graded luminance. At no point, though, should the steps go below the value of *k* times the corresponding value of L_{20}. At the end of the threshold zone, i.e. at *B*, $L_{th}(B) = k\ L_{20}(A)$.

8 Transition zone lighting during daylight

This zone provides one or more lighting levels L_{tr} intermediate between the luminance at the inner end of the threshold zone L_{th}(B) and the interior zone level L_{in}. To design this reduction in luminance, use is made of the reduction curves in figure 3 which represent the acceptable rates of decrease in luminance at various traffic speeds. The curves are applied as follows.

(a) Select the reduction curve corresponding to the highest traffic speed in the tunnel. It will be necessary to interpolate for curves related to traffic speeds other than those shown.

(b) The vertical axis of luminance should be determined by setting the 100 % level equal to the value of L_{20}(SP).

(c) Mark the points where luminances equal to L_{th}(B) and L_{in} occur on the relevant reduction curve.

(d) To fix the zero position of the curve on the horizontal axis relative to the entrance to the tunnel, the distance shown on figure 3 corresponding to the position of the luminance L_{th}(B) should be subtracted from the length of the threshold zone (see 7.1). The answer represents the distance into the tunnel at which the reduction curve commences and is the correction that has to be added to the horizontal scale for the particular tunnel under consideration, such that the new zero is at the tunnel entrance. If the correction is negative, then the reduction curve is taken as beginning outside the tunnel. The fitting of the curve at the end of the threshold zone is shown in figure 2.

(e) The portion of the reduction curve between the luminances L_{th}(B) and L_{in} shows the rate at which the luminance can be reduced through the transition zone(s) (see figure 2). The total length of the transition zone(s) can be determined from the horizontal axis.

(f) The luminance decrease is effected in a series of steps. It is recommended that the decrease between successive steps is not greater than the ratio 3 : 1, although in practice a slightly greater ratio (about 10 % greater) is allowable to facilitate the design of a simple switching arrangement. The steps should be drawn such that they form an approximation of the reduction curve with about equal portions above and below the curve. The fitting of the steps is shown in figure 12 of the worked example in appendix D.

NOTE. For reasons of economy the first step is often made 2 : 1.

(g) The steps should be arranged to follow the appropriate luminance reduction curve at all switching stages of the lighting (see clause 13).

9 Interior zone lighting during daylight

The maintained average luminance values L_{in} are given in table 4.

Table 4. Luminance in the interior zone

Speed limit		**Road lighting category**	**Average maintained luminance** L_{in}
mile/h	km/h		cd/m^2
70 and above	110 and above	Motorways	10
50 to 60	80 to 100	Category 2/1 roads and category 2/2 roads when these speed limits are applicable	5
30 to 40	50 to 70	Category 2/2 roads when these speed limits apply and category 2/3 roads	3

10 Exit zone lighting during daylight

At the exit the adaptation of the eye to the higher luminance is very rapid and extra lighting is not required to assist this adaptation. The purpose of lighting in the exit zone is:

(a) to give direct illumination of smaller vehicles which can otherwise be inconspicuous behind larger vehicles because of the glare effect of the exit;

(b) to enable drivers who are leaving the tunnel to have sufficient rear vision via their mirrors, particularly where overtaking vehicles are concerned.

A value of about five times L_{in} is sufficient and the length of this lighting zone in metres should roughly be equal to the traffic speed in kilometres per hour. In a two-way tunnel the threshold zone lighting for the opposing traffic will provide the recommended luminance.

When a one-way tunnel is likely to be used in two directions (for example during maintenance) provision may be required for additional lighting but this will usually be related to traffic travelling at reduced speed through a traffic management area.

11 Daytime uniformity ratio of luminance

Overall and longitudinal uniformities of road surface luminance are defined in BS 5489 : Part 1. The overall uniformity over the traffic lanes in all zones of a tunnel and under every stage of lighting except that at night should be not less than 0.4. The longitudinal uniformity along each traffic lane should be not less than 0.6. If these values of uniformity are met, then the uniformity of the lighting on the walls is likely also to be satisfactory.

12 Lighting during the night

12.1 Lighting in the tunnel

The maintained average road surface luminance at night should be reduced to between 2 cd/m^2 and 5 cd/m^2.

In some cases, though, it may not be possible to achieve a value as low as 5 cd/m^2 because of the practical considerations involved in complying with other recommendations in this standard; for example, to avoid flicker effects it may be necessary to reduce luminaire spacing to a value which gives an average luminance greater than 5 cd/m^2. A higher luminance than 5 cd/m^2 is permissible, but **12.2** should be noted. If a tunnel is unlit for traffic then consideration should be given to safety lighting at night for pedestrian use and for breakdowns.

These recommendations assume that the approach roads to the tunnel are lit. If, for a particular reason, they are not, e.g. from environmental considerations, then the road surface luminance in the tunnel at night should be 1 cd/m^2. This is to avoid a 'black hole effect' on leaving the tunnel. Drivers should be advised to keep their headlights on.

12.2 Lighting on the approach roads

If the tunnel is lit at night, the approach roads on either side should, unless there is a special reason, be lit for a distance of at least 200 m to an average road surface luminance which meets the recommendations of BS 5489 : Part 2 (see table 5 where the values are reproduced from BS 5489 : Part 2).

The approach road luminance should, however, be greater than one-third of that in the tunnel. If the luminance is less than one-third, then the photometric requirements of a higher lighting category should be used to determine the luminance of the approach roads over a distance of 200 m from either portal. If the luminance for category 2/1 (i.e. 1.5 cd/m^2) is still too low, then the average road luminance should be increased until it is equal to one-third of the average luminance in the tunnel. The necessary luminaire spacing can be calculated using the method described in BS 5489 : Part 2. In such cases, the higher level of lighting over the 200 m of either approach road will act as a transition between the normal road lighting and the tunnel lighting.

12.3 Uniformity ratio of night-time tunnel lighting

Overall and longitudinal uniformities should not be less than those values recommended for the lighting of the approach roads. For longitudinal uniformity the observer's distance towards the centre of the road should be $W_k/4$ m from the nearside kerb (where W_k is the road width). If these values of uniformity on the road are met, then the uniformity of the lighting on the walls is also likely to be satisfactory.

If the approach roads are not lit, then the uniformities of the road surface luminance in the tunnel should be not less than those recommended for category 2/2 (see table 5 where the values are reproduced from BS 5489 : Part 2).

Table 5. Lighting requirements for traffic routes

Category	Maintained average luminance $\bar{L}$cd/m^2	Overall uniformity ratio U_O	Longitudinal uniformity ratio U_L	Examples
2/1	1.5	0.4	0.7	High speed roads Dual carriageway roads
2/2	1.0	0.4	0.5	Important rural and urban traffic routes Radial roads District distributor roads (see BS 6100)
2/3	0.5	0.4	0.5	Connecting, less important roads Local distributor roads Residential area major access roads

13 Transition between day and night lighting

The highest level of lighting provided in the threshold and transition zones will be necessary only when the highest ambient luminances occur at the tunnel portal and its surroundings. At lower ambient luminances, and in particular at dusk, the tunnel entrance lighting needs to be reduced towards the level recommended in clause **12** for operation at night.

Conversely, the lighting should be increased at dawn.

The change should be effected in stages, the number of stages depending on the luminance in the threshold zone; the higher this luminance is, the greater the number of stages needed. It is recommended that a close, rather than a coarse, following of the change in ambient lighting be adopted. Although an instantaneous reduction of luminance level in the threshold and transition zones by a factor of five is acceptable visually, present-day practice favours smaller reductions in several stages for economic reasons as well as for reasons of greater visual comfort.

The switching stages should therefore be arranged to give the optimum arrangement so that the energy costs are reduced and the wiring costs are not excessive. Ideally, the more the steps, the greater the energy saving. In particular, it should be noted that more than half the electrical load will be attributable to the two maximum stages if the switching ratio is 3 : 1. Running costs should be weighed against the cost of extra switching equipment to provide a greater number of smaller reductions. Typical stages of lighting in the threshold and transition zones are, therefore:

full daytime 100 %
50% to 65 %
25% to 35 %
basic daytime (i.e. L_{in} throughout the tunnel)
night

Additional stages should be added if necessary. If additional lighting is provided in the exit zone, then it is switched on only for the higher stages of lighting.

It is recommended that the ratio between successive lighting stages should not exceed 3 : 1. In practice a slightly greater ratio (about 10 % greater) is allowable to facilitate the design of a simple switching arrangement. For switching between the basic daytime lighting (see **2.6**) and the next higher stage, a ratio of up to 4 : 1 is allowable. Recommendations on the switching control are given in **17.4**.

14 Avoidance of flicker effects

When luminaires are mounted in discontinuous rows along the roof or walls of a tunnel, there is a possibility of flicker causing disturbing effects to drivers passing through. Such flicker can be the result of the light sources themselves appearing and disappearing at the edge of the driver's field of view, particularly if the luminaires are cut off sharply. Images of the luminaires seen by reflection from the bonnet of the driver's own car or from the preceding vehicle can be troublesome too.

Certain ranges of frequency of flicker are more disturbing than others and then only if the driver is subjected to the effect for more than a certain length of time. The luminaire spacings to be avoided, therefore, depend on the length of the tunnel or zone and the speed of the traffic. The shaded areas of the four graphs in figure 6 indicate which are the inadmissible spacings.

The adverse effects of flicker are reduced if the length of the bright area of the luminaires is appreciable in comparison with the length of the dark space between them. In particular, if the distance between the bright areas of adjacent luminaires is less than the length of each individual bright area, then the perceived flicker effect is negligible.

In practice, it is usually only the interior zone to which these restrictions on spacing apply, as the threshold and transition zones are generally too short for flicker effects to be noticed.

15 Lighting of short tunnels

15.1 Deciding the need for lighting

Road or rail over-bridges and underpasses which are less than 25 m in length constitute the minimum stretches of covered road that are likely to be encountered. No artificial lighting is necessary by day and at night, if normal road lighting is provided, it should be arranged to penetrate sufficiently.

For greater lengths of covered road, the dark frame (see figure 7) of the roof, walls and enclosed road becomes significant in that a vehicle could be hidden in this area. The critical factor is whether vehicles (and pedestrians, where applicable) in the covered area can be seen by approaching drivers when their distance from the portal is equal to or less than the SSD.

Figure 8 provides a guide to deciding whether or not a tunnel or underpass needs lighting, and if so, what form that lighting should take.

Five items affecting the lighting of short tunnels are listed on the left hand side of the figure.

(a) Length of tunnel. Four ranges of length are given; the starting point is the box containing the length of the particular tunnel under consideration.

(b) A major consideration of the visibility in a short tunnel is whether or not the far exit is completely visible from viewpoints in front of the entrance up to a distance equal to the stopping sight distance (SSD). If the far exit is completely visible at the SSD in front of the tunnel entrance from the centre of the carriageway approaching the tunnel, the answer in line 2 of the figure is YES. Otherwise it is NO.

(c) The degree of daylight penetration at the far exit is important, too. Thus a tunnel with a large cross-sectional area, e.g. three lanes or more in width and an exit in an open area, flat or sloping downhill and south facing will admit a maximum of daylight and contribute considerably to visibility in the tunnel. On the other hand, daylight penetration could be poor where the tunnel width is two lanes or less, or the exit is in a cutting, or is surrounded by tall buildings, or the road slopes upward from the exit and the exit faces north. In most cases the decision as to whether daylight penetration is GOOD or POOR in line 3 of the figure will not be as clear cut as the examples just given. However, there should be a preponderance of factors weighing one way or the other.

(d) A high reflectance of the walls in any tunnel is important in providing additional bright background against which to perceive objects. In a short tunnel the wall reflectance assumes particular importance where the exit is not visible from the SSD in front of the tunnel entrance. A high wall reflectance will ensure that a high proportion of whatever daylight penetrates the exit will be reflected towards the drivers. This will increase the probability of objects being seen in silhouette against the walls. Walls with greater than 40 % diffuse reflectance are rated as HIGH and less than 40 % are rated as LOW (the maintenance factor has to be allowed for).

(e) The density of traffic using the tunnel is considered under two headings: HEAVY and LIGHT. HEAVY traffic implies greater than 20 000 vehicles per day (vpd). LIGHT traffic is less than 20 000 vpd. The visibility of cyclists and pedestrians, where these could be present on the carriageway, raises the probability that lighting will be necessary. Therefore, the HEAVY traffic category applies when cyclists and/or pedestrians are present.

15.2 Lighting recommendations

15.2.1 *Limited daytime lighting*

This is provided during periods when the daylight penetration does not provide a background of sufficiently high luminance to enable the silhouette effect to operate. Such conditions will arise after dawn, prior to dusk and on overcast days. The level of daytime lighting should be three times L_{in} on the road surface or 15 cd/m^2, whichever is the greater, and it should be switched on when the ambient luminance has reduced to 10 % of the maximum value of L_{20}(SP).

15.2.2 *Full daytime lighting*

The lighting should be constant throughout and at a level determined by a method similar to that employed for finding the threshold zone luminance in long tunnels.

15.2.3 *Lighting as for long tunnels*

A threshold zone luminance is determined exactly as for long tunnels. In a one-way tunnel, if its length is sufficient to accommodate the length of a threshold zone, then the remainder of the tunnel up to the exit may be lit at a lower level equivalent to the first transition zone of a long tunnel. For longer one-way tunnels, further transition zones and an interior zone can be added and this is identical to a long tunnel. Note that it may be necessary to add extra lighting at the end of the tunnel to comply with clause **10**. In two-way tunnels, threshold zones will be provided at each end but the length of the tunnel may be such that these zones meet and the lighting is constant throughout. For longer two-way tunnels, transition and interior zones will be introduced until the long tunnel situation is reached.

15.2.4 *Night-time lighting*

If the approach roads are lit, then for covered roads 25 m or greater in length it will be necessary to install night-time lighting giving a road luminance of not more than three times that on the outside road. Uniformity should be as stated in **12.3**.

15.2.5 *Lighting control system*

All daytime lighting systems will need to employ a switching system to adjust the lighting in relation to the ambient luminance.

16 Lighting the walls and ceilings

In a tunnel the important background against which objects on the carriageway are seen may be the roadway itself, the walls, or occasionally the ceiling, depending on the horizontal and vertical curvatures of the tunnel.

Often the greater part of the field of view is occupied by the walls, which therefore have a considerable influence both in revealing large objects and in determining the driver's state of adaptation in the tunnel. The luminance of the walls, especially the lower portion up to a height of at least 2 m should be not less than that of the road surface. Walls should therefore be lined with materials of high reflectance: a value of about 0.6 represents the highest available. There should then be no problem in ensuring that the recommended luminance will be achieved. The advantage of a high reflectance material is also realized in the calculation of interreflected light (see **17.3.5** and appendix E).

A highly specular wall finish should be avoided because of the tendency to produce bright streaks from the luminaires and from vehicle lights. Clearly the wall lining should be selected to be hard wearing and easily cleaned so that the benefits of the highest possible wall luminance will be more readily achieved throughout its life with the minimum regular maintenance.

If sound absorbing materials are used in the roof or ceiling, they will be difficult if not impossible to clean. Such ceilings will naturally soil quickly and become dark due to accumulation of dirt and will then act as poor reflectors of light. Consequently the lighting system should be so designed that relatively little direct light from the luminaires is received by the ceiling.

17 Achievement of required lighting levels (including emergency lighting)

17.1 Choice of lamp

17.1.1 *Fluorescent tubes*

Fluorescent tubes, because of their physical size, light output and low brightness are particularly suitable for lighting the interior zone and for the night-time lighting of the whole tunnel. Continuous or near continuous rows of luminaires should be used, which will ensure very good uniformity of lighting and absence of any flicker. The lamps should be mounted axially along the length of the tunnel.

Lamp lengths of 1500 mm or 1800 mm are generally preferred. Ambient temperatures below freezing frequently occur in tunnels in Britain. It should be ensured that lamps and control gear give satisfactory starting under these conditions.

17.1.2 *High and low pressure sodium lamps*

For higher lighting levels in the threshold and transition zones low pressure sodium (LPS) or high pressure sodium (HPS) lamps are recommended. It is often convenient to reduce the lamp wattages from zone to zone but the number of different lamp sizes should not exceed three.

With HPS lamps care should be taken to avoid glare. It may be necessary to use a system of louvres in the luminaire.

The choice of the sodium lamp should be established after consideration of the costs related to capital, energy and maintenance for the installation extended over a period of 20 years, this being a typical design life for the luminaires.

Low wattage HPS and LPS lamps may be used throughout the tunnel as an alternative to fluorescent tubes, provided that uniformity and flicker recommendations are complied with. However, the question of re-strike time should be considered, in the event of a power failure.

17.2 Location and light distribution of luminaires

17.2.1 *Location of luminaires*

Luminaires may be ceiling mounted directly above the road or side mounted on walls or in the cornices of the tunnel outside the traffic lanes. Higher utilization of the lamp flux can be achieved with ceiling mounted luminaires but side mounted luminaires may have advantages for maintenance.

Luminaires should be located whenever possible so that maintenance can be carried out with minimum interference to traffic. In two-way tunnels consideration should be given to off-setting the luminaires from the centreline of the tunnel. In multi-lane tunnels where there are several rows of luminaires, the luminaires should preferably be mounted directly over the centres of the lanes.

In some short tunnels (overbridges and underpasses), off-structure luminaires may be preferable using conventional road lighting columns and luminaires.

17.2.2 *Symmetrical light distribution*

In conventional tunnel lighting systems the luminaires are mounted with the lamp axes parallel to the run of the road so that the luminaires direct their light predominantly across the tunnel rather than along its length. The longitudinal light distribution is symmetrical while the transverse distribution can be either symmetrical or asymmetrical. The number of rows and the longitudinal spacing of luminaires in a row will depend on the lighting levels required and on the lamp wattage and number of lamps per luminaire. The spacing between luminaires in a row should be such that no annoying flicker is produced (see clause 14) and that the luminance uniformity is satisfactory. Spacings in excess of 12 m are unlikely to be satisfactory under any circumstances.

17.2.3 *Counterbeam lighting*

Whilst conventional tunnel lighting systems provide a distribution of light which is longitudinally symmetrical, counterbeam lighting systems direct more light towards the oncoming traffic than in the opposite direction, in order to increase the luminance yield of the road surface. With these systems the ratio of the road luminance to the horizontal illuminance is increased, so that a given luminance can be achieved using less lamp flux and, therefore, less power. Such a system also reduces the vertical illuminance on the front faces of objects, so that the background luminance may be reduced whilst still maintaining adequate contrast.

Not enough experience has been gained of such systems to make firm recommendations. However, because of their smaller size, which makes for better light control and reduction of glare, HPS lamps are more likely to be suitable than LPS.

17.3 Methods of calculation

17.3.1 *Luminance*

The calculation of carriageway luminance from any lighting system requires knowledge of the road surface reflection properties and the spatial light distribution from all the contributing luminaires. The calculations should be carried out as described in **B.1** to **B.7** of BS 5489 : Part 2 : 1992.

Design tables are not used for tunnel lighting design. Rather, a grid of luminance values should be evaluated over a field of calculation as defined in **B.5** of BS 5489 : Part 2 : 1992. As it is likely that luminaires will be spaced differently according to their row, the length of the calculation grid should cover one complete sequence of luminaires. From the grid of values, the average luminance and uniformities of luminance can be found. Such calculations should be carried out for all zones and stages of lighting.

The luminance of the walls cannot be calculated directly in this way because the detailed reflection characteristics of wall surfaces are not available. However, if the wall surfaces are assumed to be uniformly diffuse the following relationship between luminance and illuminance may be applied:

$$\bar{L} = \frac{ER}{\pi}$$

where

$\bar{L}$ is the maintained average luminance (in cd/m^2);

E is the maintained average illuminance (in lx);

R is the diffuse reflectance of the wall surface.

The average illuminance on the walls may be obtained from a grid of values calculated in a manner analogous to the calculation of luminance on the road surface. Alternatively, utilization factors may be used as described in **17.3.2**.

17.3.2 *Approximate method for initial design estimates*

Although the relationship between luminance and illuminance given in **17.3.1** applies to diffuse surfaces, it can be used to give approximate values of road surface luminance when initial design estimates are being prepared. The deviation of the road surface from being a perfect diffuser means that the overall accuracy of the calculated result would be expected to be within about ± 30 %. For a dry road the value of R will range from about 0.15 for a very dark carriageway to approximately 0.30 for a very light coloured carriageway. The road surface within the tunnel should be as light coloured as possible.

Probably the simplest method of calculating the maintained average direct road illuminance is from the utilization factors for the luminaires involved, with the use of the following formula:

$$E = \frac{\Phi \, U \, M_F}{W_K S}$$

where

E is the maintained average illuminance (in lx);

Φ is the initial luminous flux of the lamp (in klm);

U is the luminaire utilization factor;

M_F is the maintenance factor (see **17.3.4** and clause **18**);

W_K is the road width (in m);

S is the longitudinal spacing of luminaires (in m).

The value of U will depend on the luminaire concerned and on the installation geometry, but for preliminary calculations a value of 0.4 could be considered. This formula can also be used to calculate the maintained average direct illuminance on the walls with the appropriate luminaire utilization factors (U).

17.3.3 *Glare control*

Threshold increment (T_I), as defined in BS 5489 : Part 1, is used as the measure of disability glare in tunnels. The T_I should not exceed 15 % for all stages and zones of lighting (except the exit zone in daylight) when the luminaires and tunnel walls are in a clean state. Hence the highest acceptable value would be either:

$$T_I = \frac{65\ L_V}{(\bar{L}/M_F)^{0.8}} \text{ for values of } \bar{L} \leq 5 \text{ cd/m}^2$$

or

$$T_I = \frac{95\ L_V}{(\bar{L}/M_F)^{1.05}} \text{ for values of } \bar{L} > 5 \text{ cd/m}^2$$

where

L_V is the veiling luminance (in cd/m² per 1000 lamp lumens), as defined in BS 5489 : Parts 1 and 2;

$\bar{L}$ is the maintained average luminance (in cd/m²) of the road surface and walls forming the background;

M_F is the maintenance factor.

17.3.4 *Maintenance factor*

The maintenance factor is defined in **2.27** of BS 5489 : Part 1 : 1992 and relates to the depreciation in the photometric performance of a luminaire and lamp(s) from their initial light level (see **2.25** of BS 5489 : Part 1 : 1992) to their worst acceptable state in service.

NOTE. This factor applies to both luminaire and lamp output depreciation.

At the design stage a factor of 0.7 is recommended for the maintenance factor in calculating luminance and illuminance on the road. In wide tunnels with free flowing traffic a value of 0.85 has been found satisfactory. In practice the luminance of the walls will decrease faster than that of the road surface because both the luminaire output and the reflection factor of the walls will decrease. This can be allowed for at the design stage by assigning a maintenance factor to the wall reflectance R (see **17.3.1**) approximately equal to that applied to the luminaire output. Thus the effective maintenance factor used in the calculation of wall luminance is the square of the recommended value of 0.7, i.e. about 0.5. The maintenance procedure ultimately adopted should be such that the assumed maintenance factor is actually achieved under operational conditions (see clause **18**).

17.3.5 *Interreflected light*

In any tunnel lighting installation the actual illuminances on the road and wall surfaces will be greater than those calculated above. This is because a proportion of the light incident on one surface directly from the luminaires is reflected on to another surface and so on. This is termed interreflected light or the indirect component of the total illuminance. It can make a significant addition to the direct illuminance.

A method for calculating the interreflected component is given in appendix E; this assumes that all surfaces are diffuse reflectors. To estimate the increase in luminance the formula in **17.3.1** can be used, but no indication of the incident angular distribution of the interreflected light is given, so uniformities should be evaluated on the basis of direct light. An example of the evaluation of interreflected illuminance is included in the worked example in appendix E.

17.4 Switching control, electrical supply and emergency lighting

Selection of the appropriate switching stage in each lighting zone should preferably be automatically related to the exterior lighting level using suitable photo receivers.

The simplest systems merely switch according to the horizontal daylight illuminance measured at a selected position close to the tunnel entrance. Switching could also be done using photo detectors which monitor the vertical illuminance, in which case the visual field of the detectors should preferably include the tunnel entrance and façade. A luminance measuring device will give a closer degree of control which can be important for saving energy costs in tunnels with heavy lighting loads. Some modern equipment monitors the luminance of the tunnel approach zone by means of a television camera.

The controls will be pre-set to switch various lamps on or off at prescribed daylight levels and should incorporate a time delay of several minutes to avoid unnecessary switching owing to transient variation in the local lighting level caused by passing clouds.

Dimming can be considered if fluorescent lamps are used. High pressure sodium lamps can also be dimmed using special equipment.

The lighting load should ideally be shared between two independent sources of supply so that it is not possible for an instantaneous loss of lighting to occur. If one supply should fail, the tunnel distribution system should allow for automatic switching so that as much as possible of the normal lighting throughout the tunnel can be operated from the one remaining supply. Consideration will have to be given to reducing the speed of approaching vehicles to be compatible with the lower lighting levels.

If an adequate level of security cannot be given by the electricity supplier, it may be necessary to install a standby diesel generator to ensure that emergency lighting can be maintained. This should give the basic daytime level by day or the night-time level by night. Alternatively, if a generator is already provided to operate the pumping equipment, the emergency lighting could be included on the same supply. Any reduction from the normal lighting level will again mean that the speed of approaching traffic will have to be reduced.

If standby generation is considered not to be necessary, an emergency supply should be provided from a battery source to operate at least 10 % of the basic daytime lighting, or night-time lighting as appropriate. This lighting should be maintained for at least 1 h to allow the evacuation of the tunnel or for emergency services to be brought into use.

17.5 Daylight screens

As an alternative to providing very high levels of artificial lighting in the conventional threshold zone it may be possible to create an artificial threshold zone in the immediate approach to the tunnel in which the level of daylight is subdued by suitable screening.

The most common form of daylight screen is the open box louvre structure, usually of aluminium, set above the roadway and so designed that direct sunlight is prevented from penetrating to the road below. The design of such a screen is dependent on the geographical latitude of the tunnel and on the orientation of the approach. The screens should have apertures at least 200 mm wide in order to avoid becoming clogged by snow, which would reduce their effectiveness.

In cold conditions rain and snow passing through the louvres will be especially prone to freeze on the road below, owing to the absence of direct sunlight. Icicles can build up to a considerable size and create a hazard should they fall. Louvres can also cause difficulties with the dispersion of polluted air emerging from the tunnel.

An alternative form of daylight screen is the closed type, generally constructed of glass bricks or translucent plastics. These screens rely entirely on their diffuse transmission and for this reason their effectiveness is totally dependent on their being kept clean. Although the use of daylight screens should not be completely discounted, it seems most unlikely that a good economic case could be made for them as compared to the adoption of a conventional threshold zone lit artificially to high levels using modern, high efficiency, long-life lamps.

17.6 Reduction of the access zone luminance

In order to reduce the driver's adaptation level it is advisable to take all reasonable practical measures to reduce the luminance of the surfaces visible in the access zone. These measures include provision for the following:

(a) a dark carriageway surface;

(b) a dark tunnel façade and dark walls with a rough surface for the cutting (surfaces with a reflectance less than 0.2 should be used);

(c) tree planting;

(d) the design of the tunnel façade and treatment of its immediate surrounds which limit the effect of low angle sun and reduce the amount of sky in the visual field as far as is possible.

Example. If, in the example tunnel shown in appendix C, trees or buildings were placed behind the top of the tunnel entrance such that the sky area were halved, then the access zone luminance and hence the threshold zone luminance, would be reduced by 25 %; a considerable saving in lighting.

18 Maintenance

Atmospheric pollution in tunnels is often very high and walls and luminaires quickly become soiled. Cleaning maintenance is, therefore, particularly important and walls and luminaires should be washed frequently. The actual cleaning cycle should be decided at the design stage and related to the maintenance factor used in the calculations of the lighting levels. Consideration should also be given to the method of cleaning and to the location of the luminaires in the tunnel (see **17.2.1**).

The maintenance factor is intended to take account of the depreciation in the output of the luminaire and the reflection factors of the surfaces due to the dirt thrown up by the traffic. As recommended in **17.3.4**, a value of 0.7 is considered to be a reasonable design figure. This means that the road luminance in the tunnel should not drop below 0.7 of its initial value and the cleaning cycle should be arranged to ensure that this is the case.

The frequency of cleaning will depend on the maintenance factor, which itself will depend on the dimensions of the tunnel, the nature and density of traffic through it and the cost of maintenance in relation to other running costs. In practice, cleaning intervals range from extremes of 1 week to 6 months. It is recommended that in heavily trafficked tunnels, walls and luminaires should be cleaned at least every 2 months and reviewed as necessary to achieve the maintenance factor included in the installation design parameters. Luminaires having IP ratings of at least 55, as specified in BS 5420, are recommended but where cleaning is infrequent or high pressure jet washing and brushing systems are used, then luminaires of up to IP 66 should be used.

The use of a maintenance factor of 0.7 (or less) can, however, considerably increase the capital and energy costs if there is a large electrical load drawn by the lighting. A comparison should therefore be made between increased cleaning costs and reduced energy costs because the savings can sometimes pay for specialized cleaning vehicles or additional labour costs.

A further consideration is that the highest stages of lighting are generally only needed during the summer months and since the energy costs for the lower stages are smaller, the maintenance factor could be allowed to vary between summer and winter. More frequent cleaning in the summer could reduce the energy costs by about 15 % during this period if the improved maintenance factor had been allowed for in the design.

A check on the effectiveness of the cleaning cycle in achieving the maintenance factor during the operation of the tunnel should be carried out by measurement of the wall luminance. In a large installation continuous monitoring of the wall luminance may be linked via a computer to the switching control system and the sensor monitoring the outside luminance. By this means the factor k, i.e. L_{th}/L_{20}(SP) (see clause 4) can be kept constant as walls and luminaires get dirty. If illuminance measurement is used as a check, then this will give information on the maintenance factor applied to the road surface.

It should be noted that the walls of unlit underpasses are likely to require regular cleaning to promote daytime visibility.

Fluorescent tubes should be bulk changed after approximately 8 000 h burning. Where twin lamp luminaires are used and only one lamp kept alight for the night-time lighting, the cabling and switching should be so arranged that the night load is on average equally shared between the two lamps, so that the best overall lamp survival and lumen depreciation results are obtained.

HPS and LPS lamps will tend to fail at intervals depending on their range of switching cycles and may be replaced on an individual basis, as soon as possible after failure. At no time should the number of failed lamps remaining in the installation be allowed to mar the lighting result.

The frequency of replacement of HPS and LPS lamps will depend on their switching cycles. If the periods of operation of each lighting stage are recorded, lamp changes can be made accordingly.

19 Effect of traffic fumes and haze

The recommendations for tunnel lighting are based on the necessity of being able to perceive an object having a certain minimum contrast ratio. Under normal operating conditions the ability to meet this need will not be affected by the traffic. However, partial obscuration can arise owing to badly maintained diesel vehicles or a series of heavy vehicles climbing a gradient through the tunnel.

If the tunnel ventilation system complies with current recommendations (reference: PIARC 1979/83/87[1]), account will have been taken of conditions which could give rise to partial obscuration over a period of time. Otherwise problems with visibility may arise when the luminance in the interior zone is less than 4.5 cd/m^2. In the case of a single vehicle causing the obscuration, the sensors for the ventilation fans may not detect a local incident nor would the response of the system be sufficiently fast to be of use in clearing the fumes. As with other special cases, the lighting design would not take these incidents into account since the driver would automatically make adjustments for the varying road conditions.

With regard to the approach to the tunnel, polluted air, atmospheric haze or spray could affect the contrast of the object against the background when viewed by the driver from a distance. If these circumstances are likely to be frequent then consideration should be given to increasing the luminance in the threshold zone. It should however be examined whether the circumstances could arise on the brightest summer days because the problem could be overcome by using luminance detectors to raise the level of lighting in the threshold zone during this abnormal period.

It is unlikely that traffic fumes from polluted air would be a problem if the ventilation system has been designed to comply with the current recommendations. For existing tunnels, measurements should be taken to determine the effect of the obscuration.

---

[1] Obtainable from PIARC British National Committee Secretariat, Room 4/14, St Christopher House, London SE1 0TE.

Appendices

Appendix A. Theoretical background to the basis of tunnel lighting design

Fundamental laboratory experiments have been carried out using an adapting screen of uniform luminance in which a darker 1° square field, representing a tunnel entrance, was presented to observers for a period of 0.1 s. Within the square field was a small square 'object' with a certain luminance contrast silhouetting it against the 'tunnel entrance'. Observers were asked to state whether they could perceive the object or not. On the basis of 75 % probability of perception of the object, relationships were found which linked the necessary luminance of the 'tunnel' (i.e. the 1° square field) to the adapting screen luminance for several values of luminance contrast of the object. It was found that the ratio of the 'tunnel' luminance to the adapting screen luminance was roughly constant over a range of the adapting luminance between 100 cd/m^2 and 5000 cd/m^2. This ratio was about 1 :10 for an object contrast of 20 %.

This experiment assumed that the average luminance of the uniform screen could be taken as the adaptation level of the observer and that this was directly related to visibility. It has since been found that the visibility in the threshold zone depends on three components:

(a) the luminance directly viewed by the observer which in the case of a driver approaching a tunnel comprises the tunnel entrance itself and the road surface directly in front of it;

(b) the veiling luminance produced by the surroundings of the tunnel entrance;

(c) the effect of atmospheric haze, spray, traffic fumes, windscreen contamination, etc. in producing an additional luminous veil.

A method has been found whereby (a) and (b), as measured at actual tunnel entrances, can be related to a standard field of uniform luminance which produces the same adaptation of the observer as that which the actual tunnel entrance produces of the approaching driver. This related, though hypothetical, luminance is termed by the CIE the 'equivalent luminance of the (uniform) standard field'.

The effect of (c) can be dealt with separately and is considered in clause **19**.

Thus it is possible with a knowledge of (a) and (b) to use the original fundamental relationship to determine the tunnel threshold zone luminance under the given observation conditions for a particular object contrast. However, it has also been found that instead of having to measure (a) and (b) at a tunnel approach, which may not be practicable, it is sufficiently accurate to take the equivalent luminance of the (uniform) standard field as 1.5 times the access zone luminance (i.e. 1.5 × L_{20}).

The factors recommended in clause **6** by which L_{20} has to be multiplied to obtain L_{th}, include this factor of 1.5.

After passing the adaptation point, a driver's point of regard, at a distance ahead equal to the SSD, starts to enter the transition zones. This is where the luminance is decreased from the level at the end of the threshold zone to that of the interior zone. The maximum rate of reduction of luminance was determined in laboratory experiments as that for which no negative after-images occurred and an object remained visible as the luminance of a screen was reduced from 8000 cd/m^2. The resulting curve of time against luminance provided the basis of the luminance reduction curves in figure 3.

(Reference: CIE Publication No. 61 'Tunnel Entrance Lighting' (1984)).

Appendix B. Method of making direct measurements of access zone luminance on site

The most precise determination of access zone luminance L_{20} is by direct measurement at the time of year when its value is a maximum. This time is most likely to be around midsummer in June in Britain, but it is possible for a tunnel in winter covered in snow, to reach a higher L_{20} value. A luminance meter accepting a 20° circular field of view should be used. It should be mounted on a tripod in the centre of the carriageway approaching the tunnel at a height of 1.5 m above the road surface and aimed with the 20° field centred on the tunnel entrance. The meter and tripod should, firstly, be positioned at a distance from the portal equal to the stopping sight distance, i.e. to measure L_{20}(SP). Observations should be taken on several days when the sun is shining. Conditions with white clouds in the sky, particularly in the field of measurement, should be included as they can produce a higher value of L_{20}.

Any situation where the sun enters the 20° field of view should be excluded from measurement because of the extremely high luminance readings that will occur. (In practice drivers will cope with this situation by lowering their visors.)

Series of measurements should be taken at both ends of the tunnel around the times when the maximum L_{20} values are reached and plotted against time. In east-west tunnels it is probable that the maximum at the east portal will occur in the morning and that at the west portal in the afternoon. It is not always obvious, though, when these maxima occur, and care should be taken to check whether, for example, scattered light from haze on a shaded hillside is producing a significantly high L_{20} value at a different time of day. Once the maximum values of L_{20}(SP) have been established, measurements of L_{20} at several positions closer to the tunnel entrance should be made in order to determine the adaptation point A (see figure 1). The luminance meter should be moved towards the portal at intervals of about 10 % of the SSD, or 10 m whichever is the greater. A plot of L_{20} against distance should reveal the adaptation point A on the tunnel approach where the value of L_{20} starts to decrease significantly.

At the same time as these luminance readings are being taken, the corresponding horizontal illuminance values should be taken at an open site to act as a control. Daylighting conditions can vary rapidly and could change during a series of L_{20} measurements, in which case it may be necessary to normalize readings to the maximum illuminance. Sky luminance conditions in the field of view can also vary during a series of L_{20} measurements, so care should be taken to ensure that the determination of the adaptation point is a true one.

If a luminance meter accepting a 20° field of view is not available, then a meter with smaller field (say 3° or 1°) can be used, but it will be necessary to make several spot measurements of luminance over the 20° field and average these to give L_{20} in the manner described in appendix C.

It has so far been assumed that the L_{20} measurements are made on an existing tunnel. Where the tunnel is yet to be constructed L_{20} measurements should be made from positions corresponding to where the new road will be. The luminance meter should be aimed at the point to be occupied by the tunnel entrance. It may not be possible to position the meter precisely because of the terrain and/or trees, etc., but a reasonably close alternative can be used. If even this is difficult, then it is better not to attempt to make direct measurements of L_{20}, but to use the method described in appendix C. Measurements made on the site of an unbuilt tunnel may need to be adjusted for the eventual presence of the road surface in place of the existing terrain.

This can be done by measuring the average luminance of the area to be occupied by the road and comparing it with the luminance of a similarly orientated road in the vicinity or an appropriate luminance from the list in appendix C. If there is an appreciable difference, then a correction can be made by substituting the road luminance in a new average, weighted according to the area it occupies in the 20° field of view.

Appendix C. Determining access zone luminance by the grid method

The access zone luminance L_{20} can be calculated by the grid method which can be used either during initial design or when determining the maximum luminance for an existing tunnel. The method breaks up the field of view into small areas so that individual luminance values can be applied to each area and then an average luminance level is calculated for the whole area. The view of the tunnel as seen at the SSD from the entrance can be constructed using perspective drawings or using a computer model or it can be obtained directly with a photograph. Whichever is used the observation point should be 1.5 m above the road surface at the centre of the carriageway.

It is necessary to know the angular extent of the view so that a circle subtending 20° at the observer's eye can be superimposed. If a photograph is used it is helpful to have a reference object in the field of view to establish the angular scale. For an existing tunnel, its height H provides a suitable reference and then, together with the distance at which the picture was taken S_{SD}, an angular calibration of the photograph can be determined from the following:

$$\text{angle subtended by tunnel height} = \tan^{-1}\frac{H}{S_{SD}}$$

approximately

Where the tunnel has not been constructed, then an object of known length, e.g. a surveyor's pole, should be included in the photograph at a known distance. Failing this the angular height of the print can be calculated from the following:

$$\text{angular height of print} = 2\tan^{-1}\frac{h}{2f}$$

where

h is the height of the film negative printed (in mm);

f is the focal length of the camera lens (in mm).

With the use of an overlay, the tunnel portal can be drawn onto the photograph of the tunnel site using the appropriate scale. Similarly the road verge, retaining walls, gantries and other objects forming part of the final field of view can be added. Care should be taken to allow for any change in road level in the reconstruction. The overall accuracy of the drawing is not critical providing the main features are present to an approximate scale. The calculation of L_{20} from the photograph, drawing or computer model is carried out as follows.

(a) The limit of the field of view is added by superimposing a circle of 20° subtense centred on the tunnel portal at a height of 1.5 m from the road surface as shown in figure 9.

(b) The 20° field of view is divided into areas (see figure 10) and each area identified with a reference number or letter. A luminance value L is assigned to each area A using a measured value taken at the site or a typical value from table 6.

c) A schedule of the areas is now made up as indicated in table 7. The summation of A and AL gives the total area and the total luminance respectively; the average luminance, i.e. L_{20}, can then be found by division.

d) The effect of varying the luminance of some of the objects in the field of view can be studied. This facility can be useful when determining the finish to be used for the portal or the retaining walls. It may be found that the finish could have a significant effect on the access zone luminance. (see **17.6**).

e) The grid method can be used to investigate the adaptation as the field of view changes when approaching the tunnel. In this way the adaptation point can be found for calculating the threshold zone.

Finally it should be noted that the grid method is an approximation and the accuracy is dependent on the particular luminances used in the calculation. Table 6 gives a guide to typical values occurring in Europe. Site measurements should be taken where possible (see appendix B), particularly when the orientation of the tunnel will produce different results for each approach.

Table 6. Typical luminance values

Background	**Luminance L** cd/m^2
sky (clear)	8 000
sky (hazy, bright) occurs when facing in southerly direction	20 000
grass	2 000
hill (rock, scree)	3 500
earth/sand	3 500
tree	1 000
portal (dark)	1 000
wall (dark)	1 000
wall (light)	6 000
road (asphalt)	4 000
road (asphalt) in sun when facing in southerly direction	6 000
road (concrete)	8 000
house (brick)	3 500

NOTE. These values are for midsummer in full sun with horizontal illuminance approximately 100 000 lx. Where a surface (other than the sky) is in shadow at the time L_{20} is maximum then the above values should be multiplied by 0.25.

Appendix D. Example of tunnel lighting design

D.1 General

The following example shows how to apply the recommendations when designing a tunnel lighting system. The method used will be found to be satisfactory for a first approximation; a more detailed study can be carried out by using a computer and photometric data from an actual luminaire.

Table 7. Example of calculation for determining access zone luminance L_{20}

Area	**Background**	**Area (A)** (arbitrary units)	L cd/m^2	AL
a	sky (clear)	2 600	8 000	20 800 000
b	dark wall	1 150	1 000	1 150 000
c	dark wall over portal	300	1 000	300 000
d	road (asphalt) in sun	3 300	4 000	13 200 000
e	road in shadow	80	1 000	80 000
f	dark wall in shadow	128	250	32 000
g	house (brick) in shadow	130	875	114 000
h	trees	90	1 000	90 000
i	sandy medians	800	3 500	2 800 000
j	tunnel interior	922	—	—
Total		9 500		38 566 000

Average luminance $L_{20} = AL/A = 4060$ cd/m^2

D.2 Tunnel data

The tunnel to be considered is that shown in figure 9 which is located in an urban area. The following data will be assumed:

length	600 m
width (2 lanes + verges)	9.3 m
height	6.5 m
orientation	east - west
road surface	asphalt (R = 0.15) (see **17.3.1**)
wall surface	panels (R = 0.7)
maintenance factor	0.7

D.3 Traffic data

The following data will be assumed:

speed	70 km/h
direction	unidirectional
vehicles per day	25 000

D.4 Access zone luminance L_{20}(SP)

It is assumed that a series of site readings have been taken and an approximate field of view built up at the stopping sight distance using the method described in appendix C. The following will be used:

SSD for 70 km/h (see table 1)	90 m
luminance L_{20} at SSD (see appendix C)	4060 cd/m^2
adaptation point from portal (see figure 5):	
$d = \frac{(h - 1.5)}{\tan 10°}$	= 28.4 m

D.5 Threshold zone

From clause **6** the factor k to obtain the threshold zone luminance L_{th} from the access zone luminance L_{20} for a category 2/1 road is 0.06. Therefore the design luminance for the tunnel road surface is:

$4060 \times 0.06 = 244$ cd/m^2

The length of the threshold zone = $(S_{SD} + 20) - d$ (see **7.1**)

$= (90 + 20) - 28$

$= 82$ m

The threshold zone is assumed to have a constant luminance level although a reduction could be made if an accurate curve had been produced for the access zone luminance.

D.6 Transition, interior and exit zones

The maximum step between zones is 3 : 1, hence the values given in table 8 could be considered.

Table 8. Possible values for transition, interior and exit zones

Zone	Maintained average luminance cd/m^2	% of L_{20}	Length m
Threshold	244	6.0	82
1st Transition	81	2.0	85
2nd Transition	27	0.7	85
Interior	10	0.2	278
Exit	50	-	70
Total tunnel length			600

The interior zone luminance is taken from table 4 for specially heavy traffic. The transition zone lengths are obtained from the reduction curve given in figure 3. The exit zone has been derived as indicated in clause **10**.

The steps calculated above represent the minimum possible to reduce the external luminance from 4060 cd/m^2 to the tunnel interior luminance of 10 cd/m^2. Further calculations may show that the theoretical values should be adjusted to allow for selected lamp sizes and luminaire spacings.

D.7 Luminaires

D.7.1 *Interior zone*

The interior zone should be considered to extend the full length of the tunnel since at night or during periods of poor daylight there will not be a need for reinforced lighting. In order to give a continuous mounting arrangement it is proposed to use fluorescent lamps.

From **17.3**, maintained average road luminance $\bar{L} = \frac{ER}{\pi}$ and $E = \frac{\Phi U M_F}{W_K S}$

where S = 1 m.

For a first approximation a utilization factor of 0.4 will be used. Hence the flux ϕ per metre is given by the equation:

$$\varphi = \frac{\pi L W_K}{R U M_F}$$

$$= \frac{\pi \times 10 \times 9.3}{0.15 \times 0.4 \times 0.7}$$

$$= 6955 \text{ lm/m}$$

The calculated spacing for twin lamp luminaires would be as given in table 9.

Table 9. Calculated spacing for twin lamp luminaires

Lamp W	Luminaire length m	Initial luminous flux of the luminaire lm	Spacing m
2 × 58	1.5	10 200	1.47
2 × 65	1.5	9 800	1.41

If a space is not required between each luminaire, the 2 × 58 W luminaire would give the necessary road luminance.

D.7.2 *Threshold, transition and exit zones*

The threshold and transition zones are calculated in a similar manner but an allowance is made for the contribution from the twin fluorescent luminaires. It is proposed to use twin high pressure sodium lamps in each luminaire for the zones as shown in table 10.

Table 10. Calculation of threshold, transition and exit zones

Zone	Lamp type SON/T W	Luminaire length m	Initial luminous flux of the luminaire lm
Threshold	2 × 400	1.6	93 000
1st transition and exit	2 × 250	1.6	50 000
2nd transition	2 × 150	1.6	28 000

The number of rows and spacing for each zone are given in table 11.

In order to give a regular arrangement, the luminaire spacing should be the same. The most suitable spacing which would allow access to the ends of the luminaires would be 1.70 m for the HPS. With a correction for the spacing and the addition of the contribution from the fluorescent luminaires, the maintained average luminance values become:

threshold	246 cd/m^2
1st transition	95 cd/m^2
2nd transition	33 cd/m^2
interior	10 cd/m^2
exit	52 cd/m^2

A more accurate calculation should now be performed using a computer and actual photometric data. The uniformity of road surface luminance and the wall luminance should also be examined. A common luminaire spacing should be used for all luminaires in order to give a regular arrangement.

However, if the calculation is continued with the initial values, the stage switching can be determined, as given in table 12.

Stage 5 has been introduced to decrease the energy costs and to take advantage of switching out one of the three rows in the threshold zone. Stage 1 represents the reduced switching for night-time (one of the two lamps in each of the twin luminaires would be switched out).

Figures 11 and 12 indicate the tunnel lighting arrangement and the luminance levels plotted on the reduction curve for stage 6 respectively.

Table 11. Rows and spacing for each zone

Zone	Maintained average luminance cd/m^2	Initial luminous flux/m of the luminaire lm	Rows	Spacing m
Threshold	236	164 000	3	1.7
1st transition	72	50 000	2	2.0
2nd transition	17	12 000	1	2.3
Exit	40	28 000	1	1.8

Table 12. Calculation of stage switching

Stage	Threshold cd/m^2	1st transition cd/m^2	2nd transition cd/m^2	Interior cd/m^2	Exit cd/m^2
6	246	95	33	10	52
5	167	95	33	10	52
4	89	52	26	10	10
3	30	30	10	10	10
2	10	10	10	10	10
1	5	5	5	5	5

Appendix E. Calculation of interreflected light in a tunnel

This method of calculation is based on the established technique used for room interiors. It is a method in which the final 'steady-state' luminances of the wall, roof and road are considered. It is necessary to know the initial average illuminances (directly with no interreflection) over the walls, roof and road and the diffuse reflectances of these surfaces. The maintenance factor for the surface of the walls (and roof) should be taken into account (see **17.3.4**). The following notation is used in the subsequent formulae:

$E_0(\ldots)$	depicts the initial (or direct) average illuminance on a given surface, e.g. E_0(road) is the average illuminance over the road surface taken from wall to wall, i.e. including the hard shoulders;
$E(\ldots)$	depicts the final average illuminance on the given surface, e.g. E(walls) is the final average illuminance over the walls;
$R(\ldots)$	depicts the diffuse reflection factor of the given surface, e.g. R(roof) is the diffuse reflection factor of the tunnel roof.

If H and W are the height and width of the tunnel respectively (in metres), the final average illuminances over the road, walls and roof, i.e. direct and interreflected, are given by:

$$E(\text{road}) = \frac{\{(G - FC)\,E_0\,(\text{road}) + 2\,HF(1 + D)\,E_0\,(\text{walls})/W + (FC + GD)\,E_0(\text{roof})\}}{G(1 - BD) - F\{A(1 + D) + C(1 + B)\}}$$

$$E(\text{walls}) = \frac{[W(A + BC)\,E_0\,(\text{road}) + 2H(1 - BD)\,E_0\,(\text{walls}) + W(C + AD)\,E_0\,(\text{roof})]}{2H\,[G(1 - BD) - F\,\{A(1 + D) + C(1 + B)\}]}$$

$$E(\text{roof}) = \frac{\{(AF + BG)\,E_0\,(\text{road}) + 2HF(1 + B)\,E_0\,(\text{walls})/W + (G - FA)\,E_0\,(\text{roof})\}}{G(1 - BD) - F\{A(1 + D) + C(1 + B)\}}$$

where

$$A = [1 + (H/W) - \sqrt{\{(H/W)^2 + 1\}}]R\,(\text{road})$$

$$B = [\sqrt{[(H/W)^2 + 1]} - (H/W)]\,R(\text{road})$$

$$C = A\left\{\frac{R(\text{roof})}{R(\text{road})}\right\}$$

$$D = B\left\{\frac{R(\text{roof})}{R(\text{road})}\right\}$$

$$F = \frac{AW}{2H}\left\{\frac{R(\text{walls})}{R(\text{road})}\right\}$$

$$G = 1 - R(\text{walls})\left[1 - \frac{AW}{H}\left\{\frac{1}{R(\text{road})}\right\}\right]$$

The average interreflected illuminances can then be found by subtracting the initial from the final illuminances, i.e. $E(\ldots) - E_0(\ldots)$ for each surface.

The additional luminance resulting from this interreflected component can be estimated from the relationship given in **17.3.1**.

This calculation method assumes that all the surfaces are uniform diffusers and that the tunnel is straight and of rectangular cross section. It also assumes that all the surfaces are evenly illuminated, but non-uniform illuminance, e.g. the lower part of the walls being much brighter than the upper part, has only a small effect on the interreflected contribution to the road and may be ignored. The direct illuminance on the walls, E_0(walls), should be the average over the total wall area.

An estimation of the distribution of the interreflected light can be derived as follows.

With reference to figure 13, the interreflected illuminance E_p at any point p on the road surface is given by:

$$E_p = \frac{\pi L_W}{2}(2 - \cos\gamma_1 - \cos\gamma_2) + \\ + \frac{\pi L_R}{2}(\cos\gamma_1 + \cos\gamma_2)$$

where

L_W is the final average luminance of the walls (in cd/m^2);

L_R is the final average luminance of the roof (in cd/m^2);

γ_1 and γ_2 are the angular subtenses of the two walls.

Similarly the distribution of interreflected light up the walls can be calculated.

The results for the interior zone of the example tunnel used in appendix D are:

location of lighting	interior zone	
tunnel geometry	tunnel width	9.3 m
	tunnel height	6.5 m
tunnel reflectances	reflectance of the road	0.15
	reflectance of the walls	0.5
	reflectance of the roof	0.15
average direct illuminances	direct road illuminance	209 lx
	direct wall illuminance	90 lx
	direct roof illuminance	0 lx
average total illuminances	total road illuminance	243 lx
	total wall illuminance	125 lx
	total roof illuminance	49 lx

Interreflected illuminance contributions to the tunnel surfaces are as given in table 13.

Table 13. Interreflected illuminance contributions

On the road		On the walls	
Distance from wall m	**Illuminance** lx	**Height above road** m	**Illuminance** lx
0.24	39	0.33	38
0.70	37	0.98	38
1.17	36	1.63	37
1.63	35	2.28	37
2.10	33	2.93	36
2.56	32	3.58	35
3.03	32	4.23	34
3.49	31	4.88	33
4.42	30	5.53	32
		6.18	30

NOTE. The reflectance of the walls includes the maintenance factor.

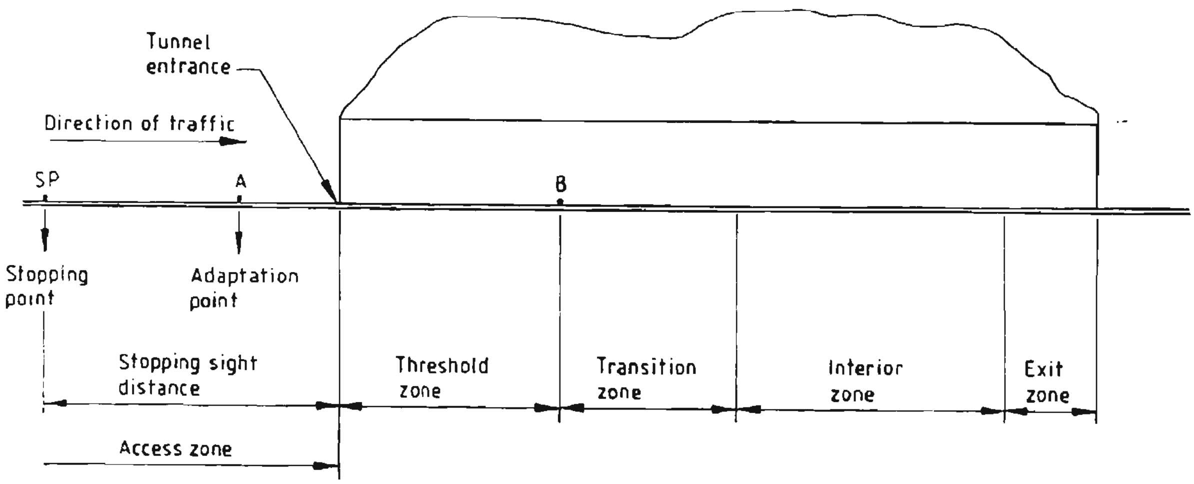
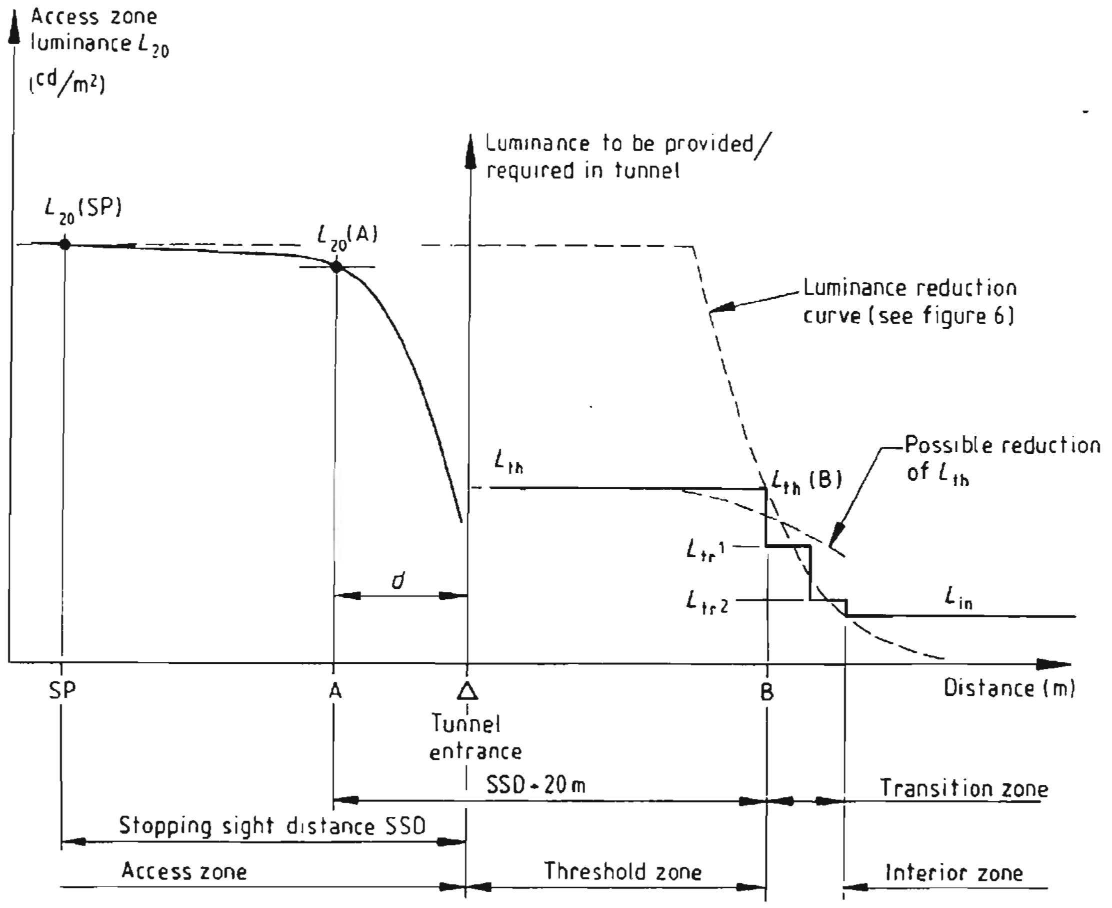
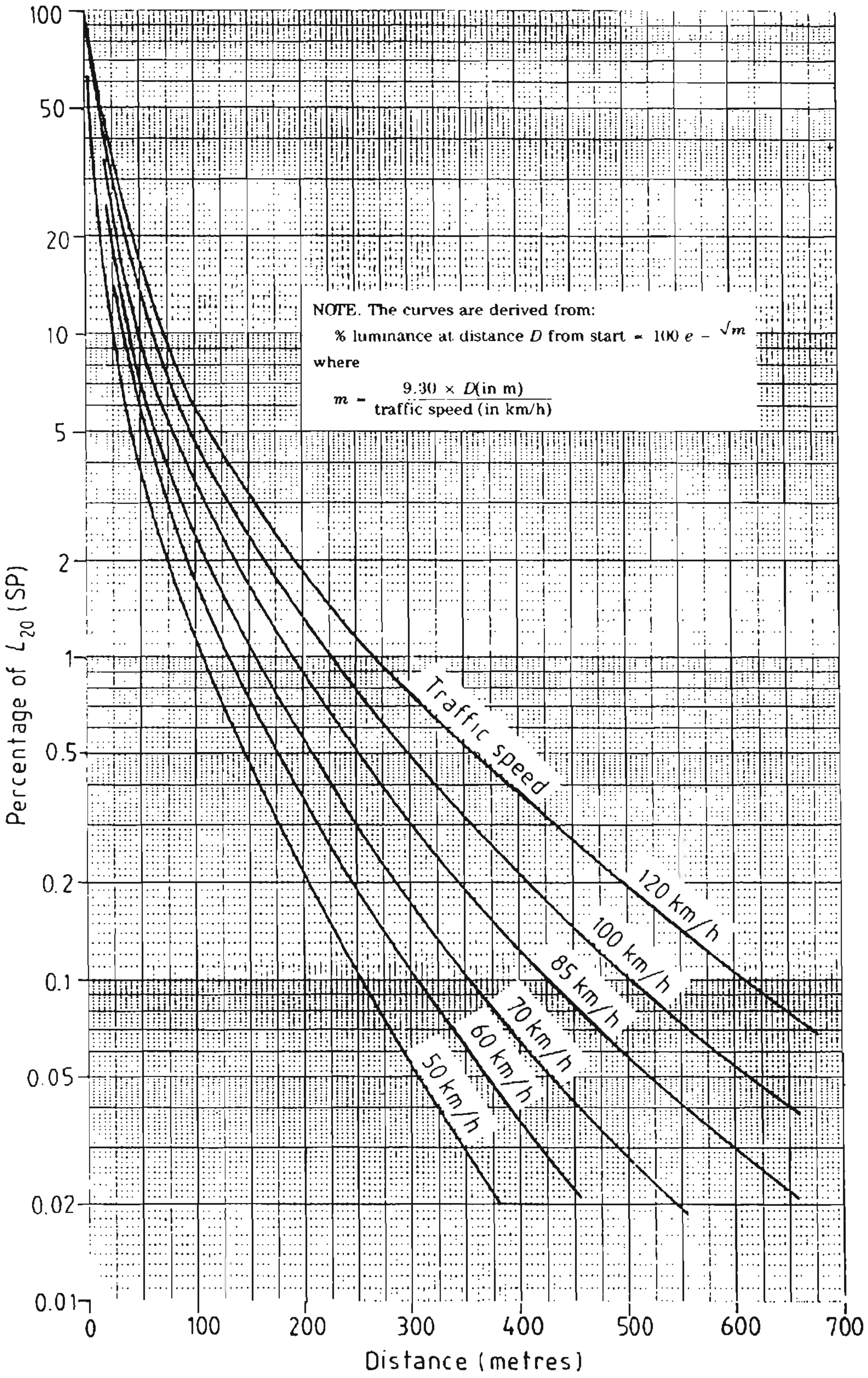


Figure 1. Longitudinal cross section of one-way tunnel



d	is the distance from adaptation point A to tunnel entrance (in m);
L_{20}(SP)	is the particular value of access zone luminance L_{20} at the stopping point SP;
L_{20}(A)	is the luminance at adaptation point A;
L_{th}	is the background luminance required in the threshold zone;
L_{th}(B)	is the luminance at the inner end B of the threshold zone;
L_{tr1}, L_{tr2}	are the luminances in the transition zone;
L_{in}	is the luminance in the interior zone.

Figure 2. Relationship between luminances in the access zone and in the tunnel zones



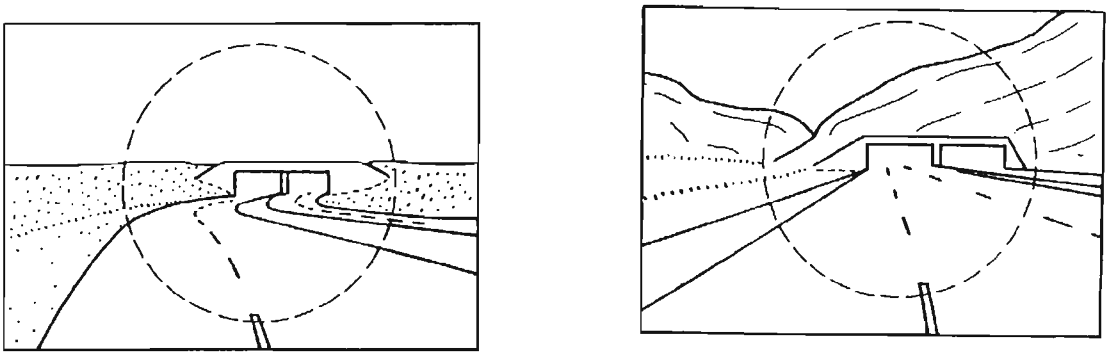
NOTE. The curves are derived from:

% luminance at distance D from start $= 100\,e^{-\sqrt{m}}$

where

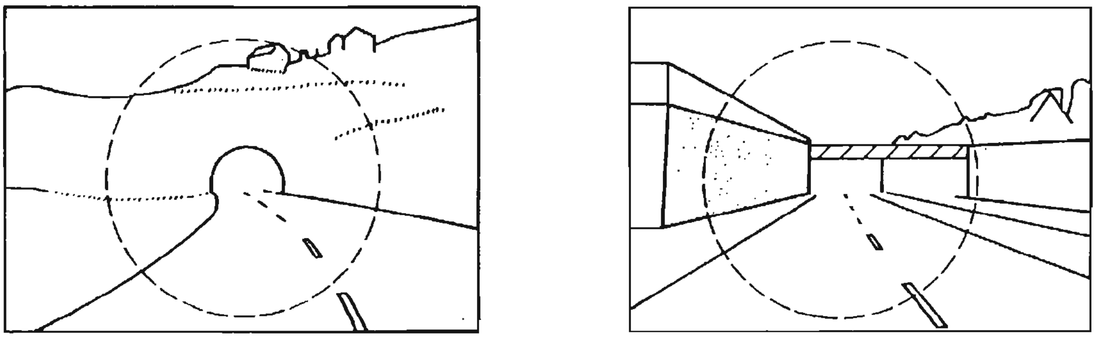
$$m = \frac{9.30 \times D(\text{in m})}{\text{traffic speed (in km/h)}}$$

Figure 3. Luminance reduction curves for the transition zone



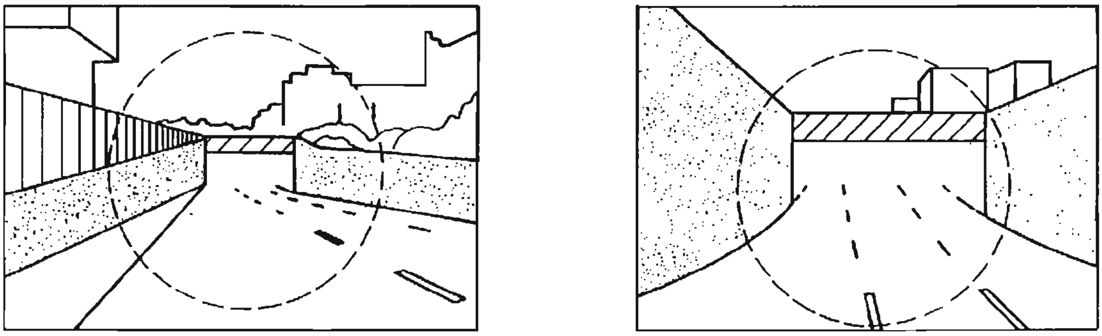
160 m distance.
L_{20} driving north 5000 cd/m^2
L_{20} driving south 7500 cd/m^2

90 m distance.
L_{20} driving north 4000 cd/m^2
L_{20} driving south 5500 cd/m^2



90 m distance.
L_{20} driving north 3000 cd/m^2
L_{20} driving south 3000 cd/m^2

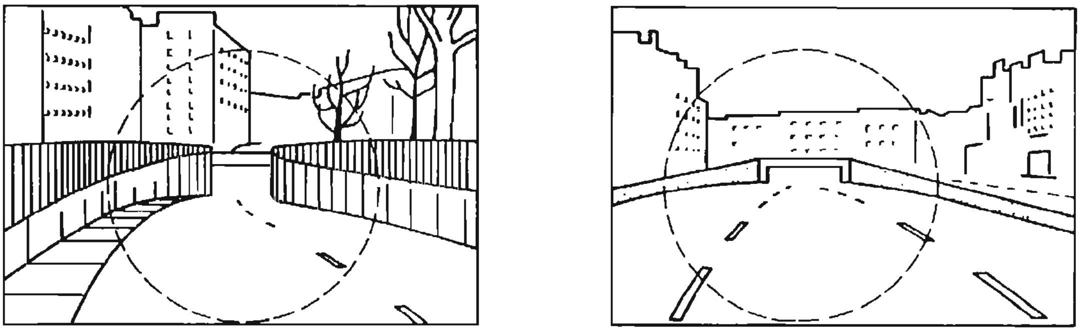
90 m distance.
L_{20} driving north 4500 cd/m^2
L_{20} driving south 7000 cd/m^2



90 m distance.
L_{20} driving north 3500 cd/m^2
L_{20} driving south 5500 cd/m^2

50 m distance.
L_{20} driving north 3000 cd/m^2
L_{20} driving south 4000 cd/m^2

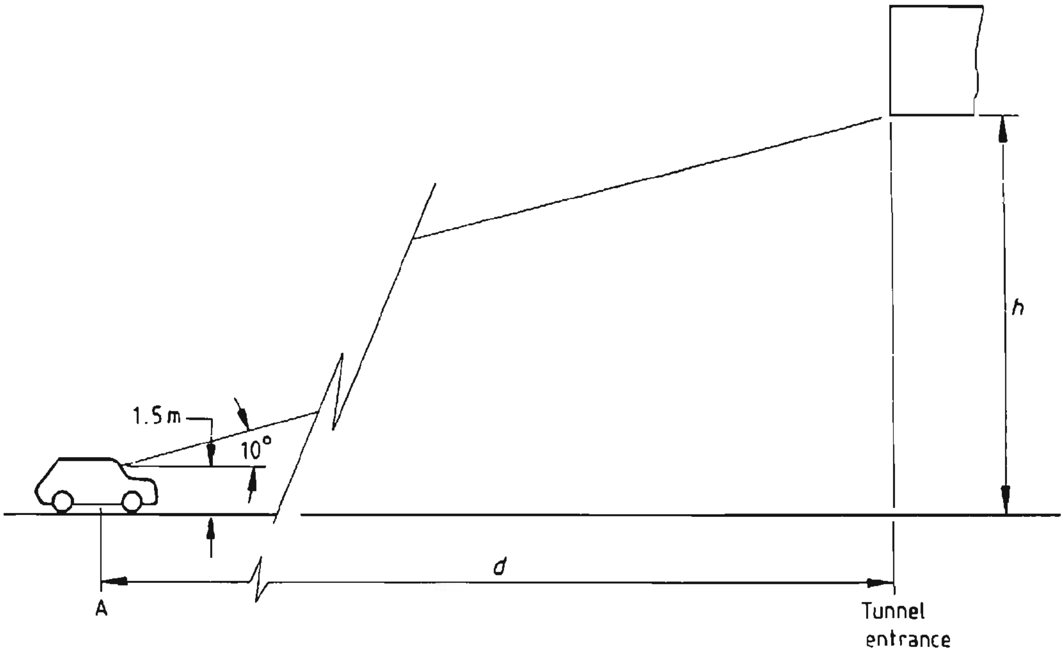
Figure 4. Examples of tunnel approaches giving access zone luminances to be used



90 m distance.
L_{20} driving north 3000 cd/m^2
L_{20} driving south 4000 cd/m^2

160 m distance.
L_{20} driving north 4500 cd/m^2
L_{20} driving south 6500 cd/m^2

Figure 4. Examples of tunnel approaches giving access zone luminances to be used (*concluded*)



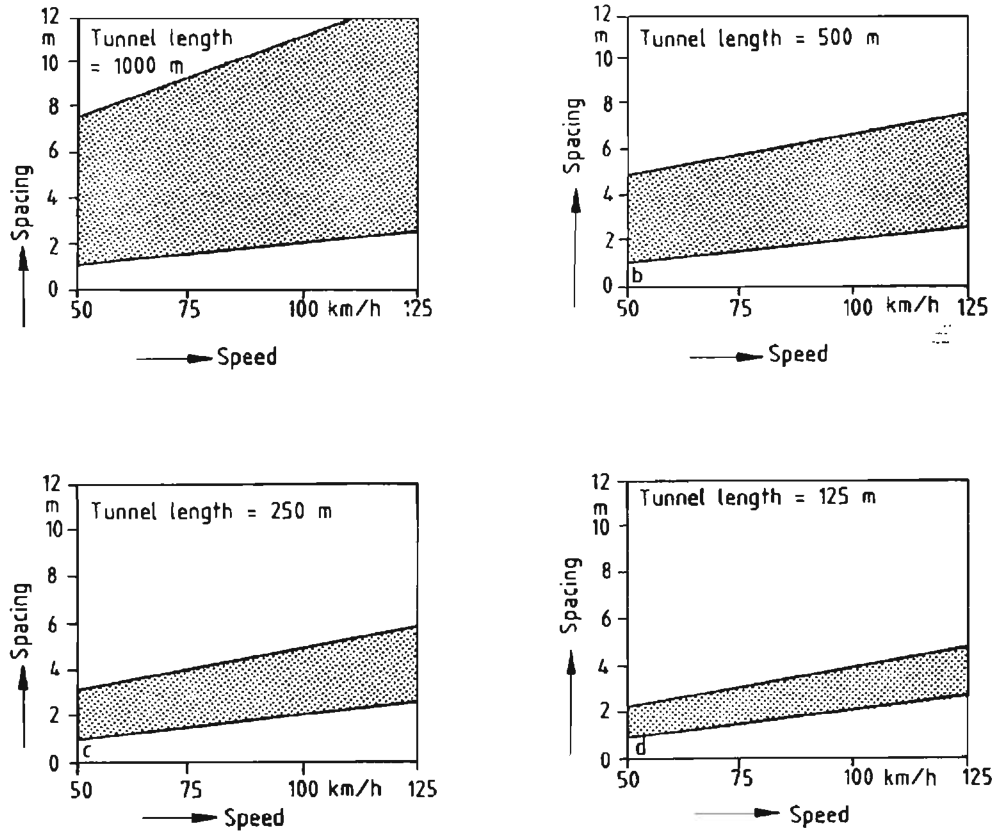
$$d = \frac{h - 1.5}{\tan 10°}$$

where

d is the tunnel distance from A to tunnel entrance (in m)

h is the height to the top of the tunnel mouth (in m)

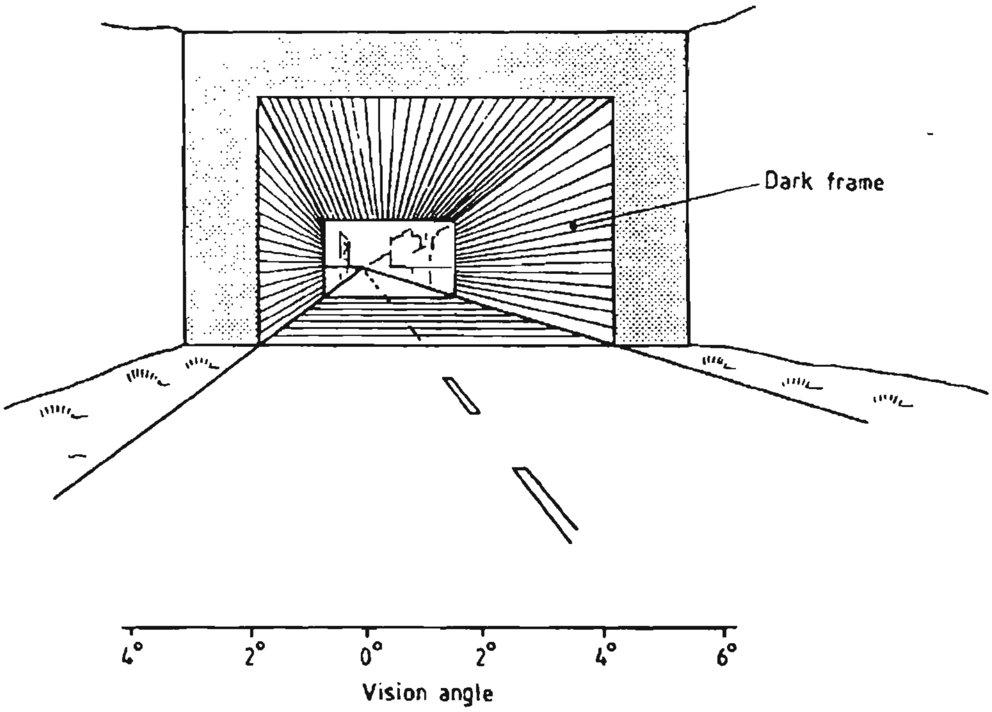
Figure 5. Geometric method used to locate the adaptation point (A) in the absence of site luminance readings (see 7.2)



NOTE. The above applies when the length of the bright area of each luminaire is less than the length of the dark space between them.

(Reference: Walthert, R. 'Tunnel lighting systems'. International Lighting Review, 4, 112 (1977))

Figure 6. Effect of tunnel length on luminaire spacings to be avoided with regard to disturbing flicker (shaded areas)



Tunnel dimensions:

- 100 m long
- 7 m wide
- 5 m high

Viewed from 70 m with the driver's eye height 1.5 m above the road surface.

Figure 7. View of a short tunnel showing the dark frame

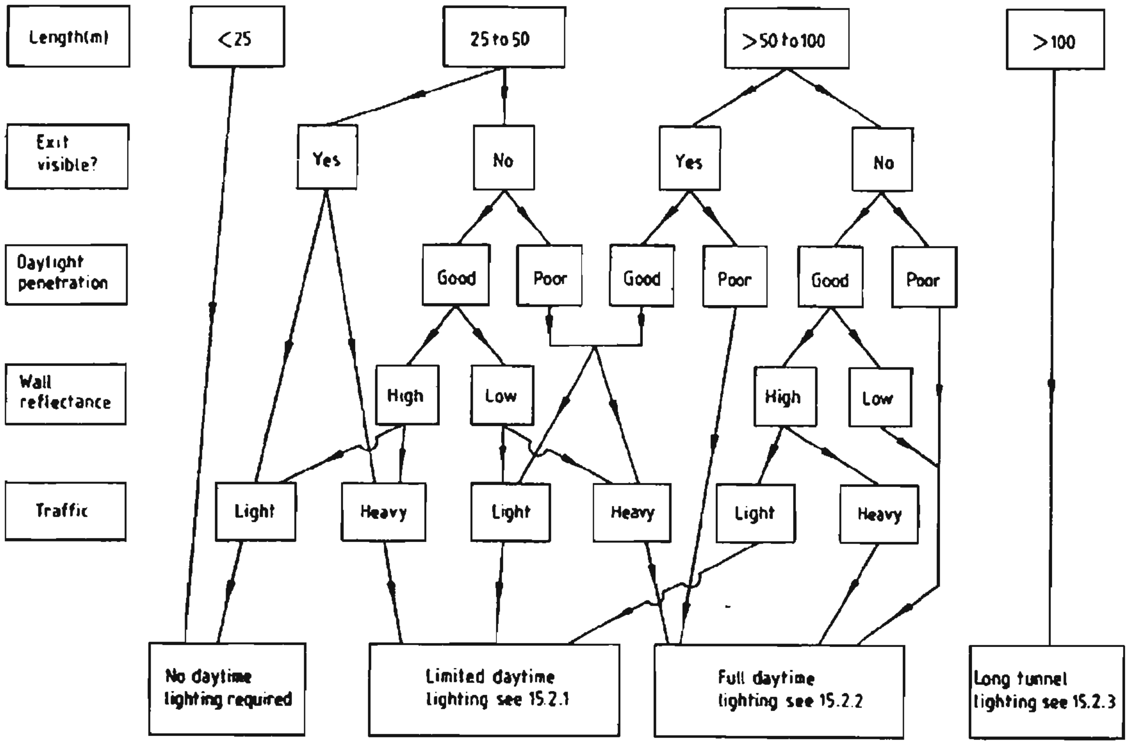


Figure 8. Daytime lighting of short tunnels

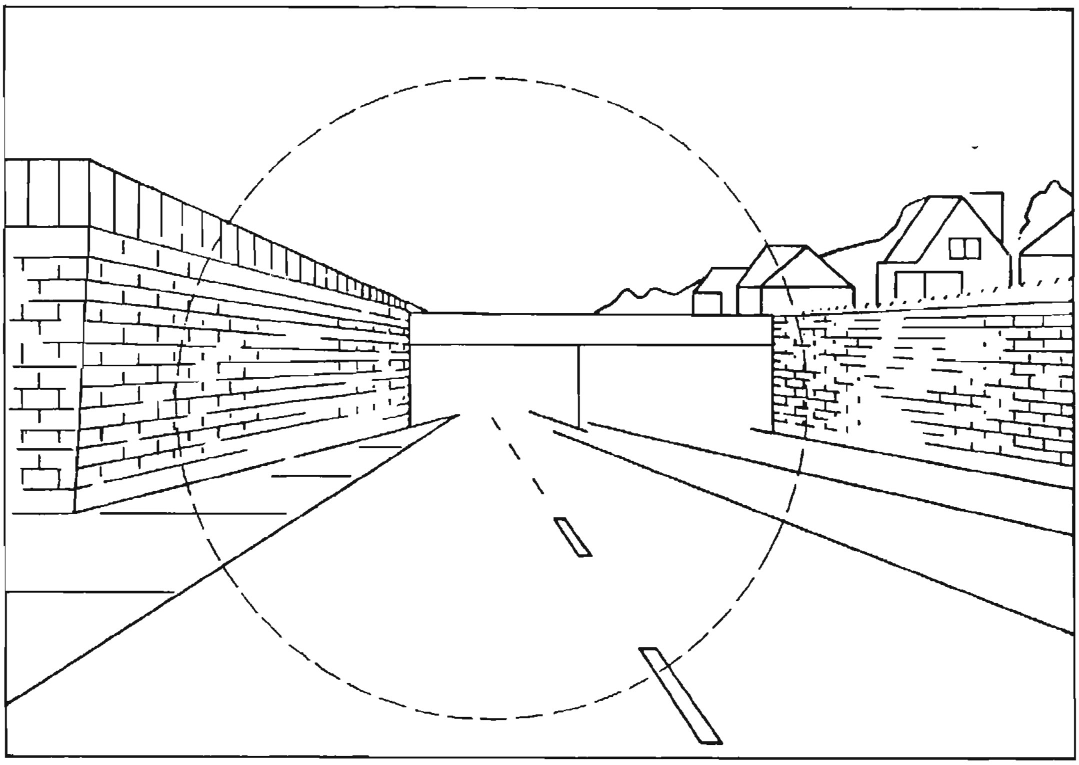


Figure 9. Perspective view of tunnel entrance with superimposed 20 ° subtense circle

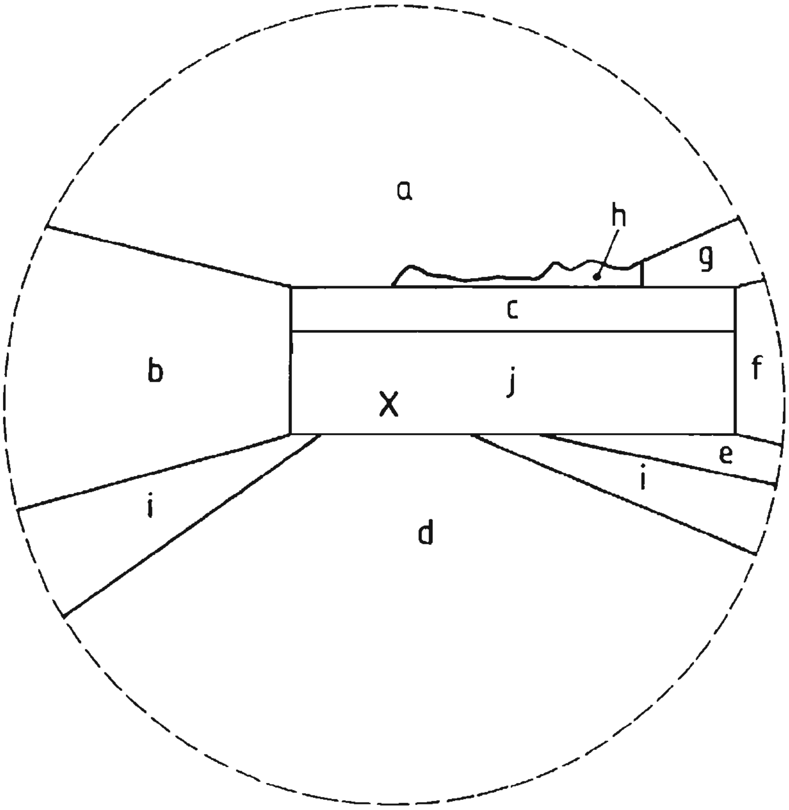


Figure 10. 20 ° field of view divided into assessment areas

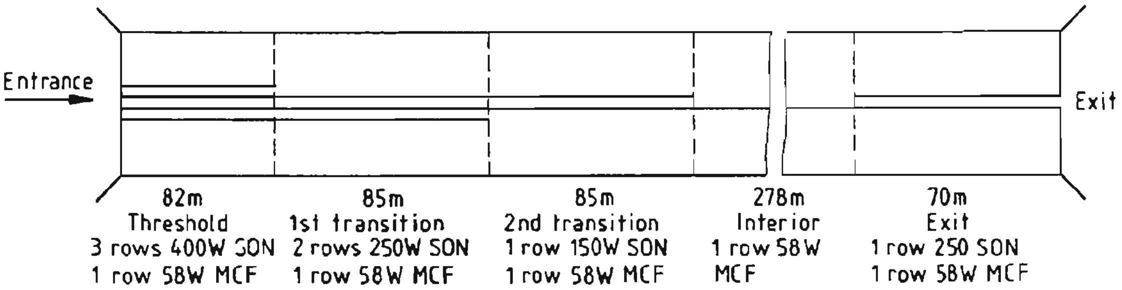
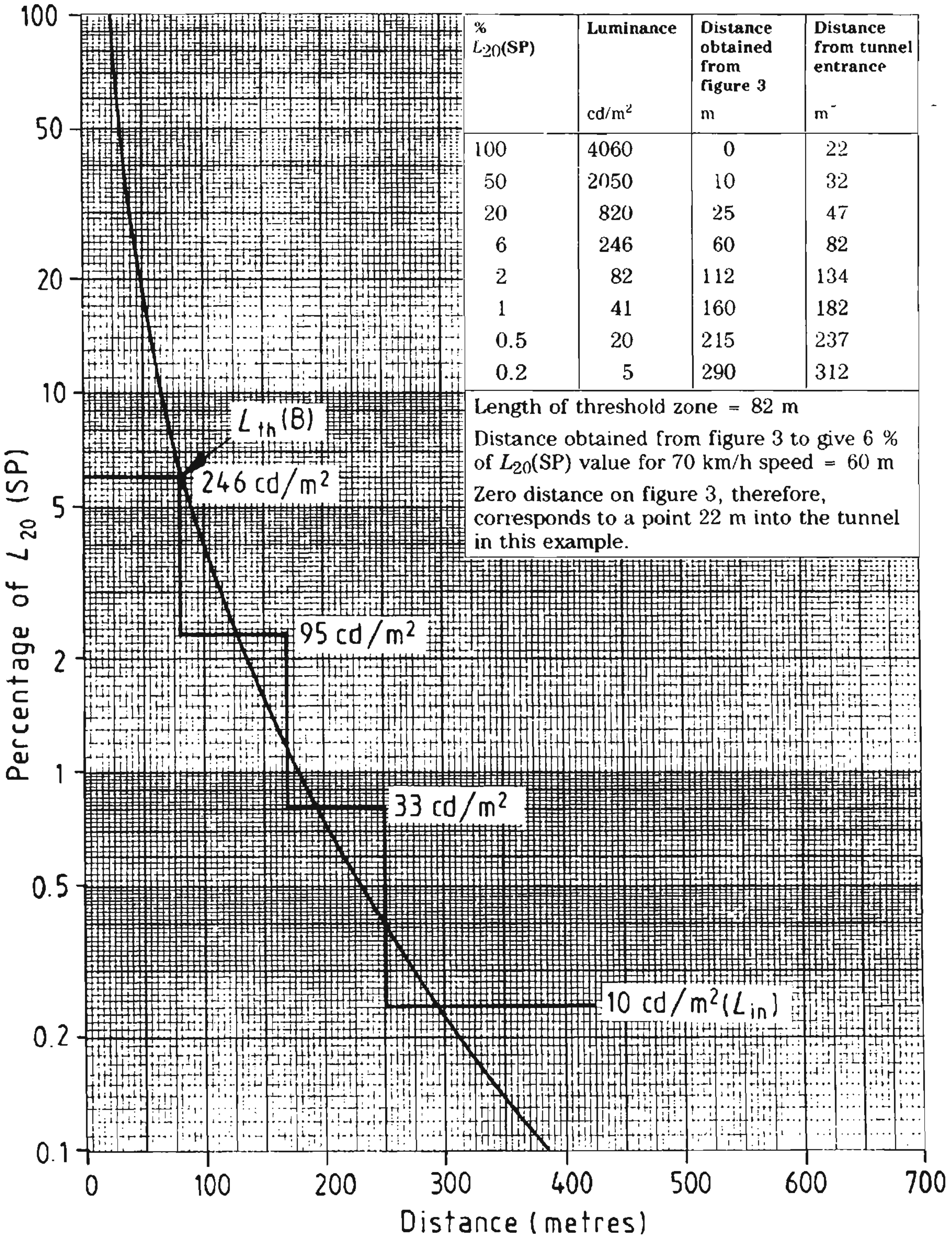


Figure 11. Tunnel lighting arrangement



% L_{20}(SP)	Luminance cd/m²	Distance obtained from figure 3 m	Distance from tunnel entrance m
100	4060	0	22
50	2050	10	32
20	820	25	47
6	246	60	82
2	82	112	134
1	41	160	182
0.5	20	215	237
0.2	5	290	312

Length of threshold zone = 82 m

Distance obtained from figure 3 to give 6 % of L_{20}(SP) value for 70 km/h speed = 60 m

Zero distance on figure 3, therefore, corresponds to a point 22 m into the tunnel in this example.

Figure 12. Luminance levels plotted on reduction curve for stage 6

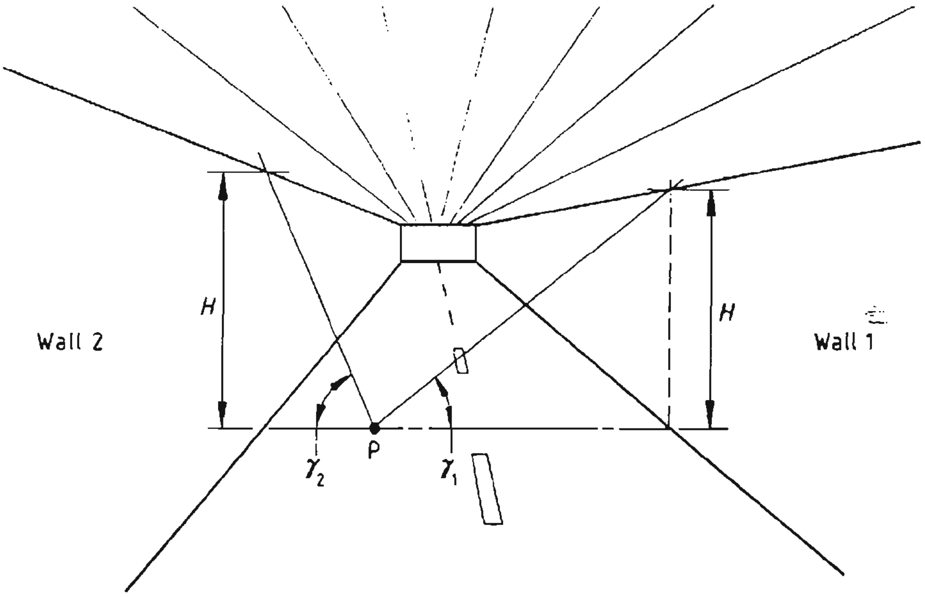


Figure 13. Calculation of interreflected light at point P

Publication(s) referred to

BS 5225 Photometric data for luminaires
Part 1 Photometric measurements

BS 5420 Specification for degrees of protection of enclosures of switchgear and controlgear for voltages up to and including 1000 V a.c. and 1200 V d.c

BS 5489 Road lighting
Part 1 Guide to the general principles
Part 2 Lighting for traffic routes

BS 6100 Glossary of building and civil engineering terms
Subsection 2.4.1 Highway engineering

Department of Transport Standard TD 9/81, Road layout and geometry – Highway link design, August 1981 and Amendment No. 1 January 1985

PIARC 1979/83/87, PIARC Road Tunnels Technical Committee Reports at Vienna (1979), Sydney (1983) and Brussels (1987)

CIE Publication No. 61 'Tunnel Entrance Lighting' (1984)

Walthert, R. 'Tunnel lighting systems' International Lighting Review, 4, 112 (1977)

Issue 2, May 1996

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Contract requirements

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the responsible technical committee, the identity of which can be found on the inside front cover. Tel: 0181 996 9000; Fax: 0181 996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services, Sales Department at Chiswick: Tel: 0181 996 7000; Fax: 0181 996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library, the Standardline Database, the BSI Information Technology Service (BITS) and its Technical Help to Exporters Service. Contact the Information Department at Chiswick: Tel: 0181 996 7111; Fax: 0181 996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Customer Services, Membership at Chiswick: Tel: 0181 996 7002; Fax: 0181 996 7001.

Copyright

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

If permission is granted, the terms may include royalty payments or a licensing agreement. Details and advice can be obtained from the Copyright Manager, BSI, 389 Chiswick High Road, London W4 4AL.

BSI
389 Chiswick High Road
London
W4 4AL

ISBN 0 580 20900 8

AMD 9013

Amendment No. 1
published and effective from 15 May 1996
to BS 5489 : Part 7 : 1992

Road lighting

Part 7. Code of practice for the lighting of tunnels and underpasses

---

Instructions for replacement of pages

Where only one of the two pages on each sheet has been updated, the other page has been reprinted.

Front cover and inside front cover	Replace the pages
a	Insert the page immediately after the inside front cover
20	Replace the page
32	Replace the page
Back cover	Replace the page

You may wish to retain the superseded pages, e.g. for reference purposes, if so please mark them 'Superseded by issue X', where 'X' is the appropriate issue number. If you do not wish to retain the superseded pages, please destroy them.

BRITISH STANDARD

BS 5489 :
Part 7 : 1992

Incorporating
Amendment No. 1

Road lighting

Part 7. Code of practice for the lighting of tunnels and underpasses

S

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Electrical Illumination Standards Policy Committee (LGL/-) to Technical Committee LGL/23, upon which the following bodies were represented:

Automobile Association
British Lighting Association for the Preparation of Standards (Britlaps)
British Precast Concrete Federation Ltd.
Chartered Institution of Building Services Engineers
Council for the Protection of Rural England
County Surveyors' Society
Department of Transport
Institution of Civil Engineering Surveyors
Institution of Civil Engineers
Institution of Electrical Engineers
Institution of Lighting Engineers
Institution of Mechanical Engineers
Lighting Industry Federation Ltd.
Royal Fine Art Commission
Scottish Office (Building Directorate)

This British Standard, having been prepared under the direction of the Electrical Illumination Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 August 1992

First published as CP 1004 February 1971
Second edition as BS 5489 : Part 7 October 1990
Third edition August 1992

The following BSI references relate to the work on this standard:
Committee reference LGL/23
Draft announced in *BSI News* March 1992
ISBN 0 580 20900 8

Amendments issued since publication

Amd. No.	Date	Text affected
9013	May 1996	Indicated by a sideline in the margin

Summary of pages

The following table identifies the current issue of each page. Issue 1 indicates that a page has been introduced for the first time by amendment. Subsequent issue numbers indicate an updated page. Vertical sidelining on replacement pages indicates the most recent changes (amendment, addition, deletion).

Page	Issue	Page	Issue
Front cover	2	18	original
Inside front cover	2	19	original
a	1	20	2
b	blank	21	original
1	original	22	original
2	original	23	original
3	original	24	original
4	original	25	original
5	original	26	original
6	original	27	original
7	original	28	original
8	original	29	original
9	original	30	original
10	original	31	original
11	original	32	2
12	original	33	original
13	original	34	original
14	original	35	original
15	original	36	original
16	original	Inside back cover	original
17	original	Back cover	2

positions closer to the tunnel entrance should be made in order to determine the adaptation point A (see figure 1). The luminance meter should be moved towards the portal at intervals of about 10 % of the SSD, or 10 m whichever is the greater. A plot of L_{20} against distance should reveal the adaptation point A on the tunnel approach where the value of L_{20} starts to decrease significantly.

At the same time as these luminance readings are being taken, the corresponding horizontal illuminance values should be taken at an open site to act as a control. Daylighting conditions can vary rapidly and could change during a series of L_{20} measurements, in which case it may be necessary to normalize readings to the maximum illuminance. Sky luminance conditions in the field of view can also vary during a series of L_{20} measurements, so care should be taken to ensure that the determination of the adaptation point is a true one.

If a luminance meter accepting a 20° field of view is not available, then a meter with smaller field (say 3° or 1°) can be used, but it will be necessary to make several spot measurements of luminance over the 20° field and average these to give L_{20} in the manner described in appendix C.

It has so far been assumed that the L_{20} measurements are made on an existing tunnel. Where the tunnel is yet to be constructed L_{20} measurements should be made from positions corresponding to where the new road will be. The luminance meter should be aimed at the point to be occupied by the tunnel entrance. It may not be possible to position the meter precisely because of the terrain and/or trees, etc., but a reasonably close alternative can be used. If even this is difficult, then it is better not to attempt to make direct measurements of L_{20}, but to use the method described in appendix C. Measurements made on the site of an unbuilt tunnel may need to be adjusted for the eventual presence of the road surface in place of the existing terrain.

This can be done by measuring the average luminance of the area to be occupied by the road and comparing it with the luminance of a similarly orientated road in the vicinity or an appropriate luminance from the list in appendix C. If there is an appreciable difference, then a correction can be made by substituting the road luminance in a new average, weighted according to the area it occupies in the 20° field of view.

Appendix C. Determining access zone luminance by the grid method

The access zone luminance L_{20} can be calculated by the grid method which can be used either during initial design or when determining the maximum luminance for an existing tunnel. The method breaks up the field of view into small areas so that individual luminance values can be applied to each area and then an average luminance level is calculated for the whole area. The view of the tunnel as seen at the SSD from the entrance can be constructed using perspective drawings or using a computer model or it can be obtained directly with a photograph. Whichever is used the observation point should be 1.5 m above the road surface at the centre of the carriageway.

It is necessary to know the angular extent of the view so that a circle subtending 20° at the observer's eye can be superimposed. If a photograph is used it is helpful to have a reference object in the field of view to establish the angular scale. For an existing tunnel, its height H provides a suitable reference and then, together with the distance at which the picture was taken S_{SD}, an angular calibration of the photograph can be determined from the following:

$$\text{angle subtended by tunnel height} = \tan^{-1}\frac{H}{S_{SD}}$$

approximately

Where the tunnel has not been constructed, then an object of known length, e.g. a surveyor's pole, should be included in the photograph at a known distance. Failing this the angular height of the print can be calculated from the following:

$$\text{angular height of print} = 2\tan^{-1}\frac{h}{2f}$$

where

h is the height of the film negative printed (in mm);

f is the focal length of the camera lens (in mm).

With the use of an overlay, the tunnel portal can be drawn onto the photograph of the tunnel site using the appropriate scale. Similarly the road verge, retaining walls, gantries and other objects forming part of the final field of view can be added. Care should be taken to allow for any change in road level in the reconstruction. The overall accuracy of the drawing is not critical providing the main features are present to an approximate scale. The calculation of L_{20} from the photograph, drawing or computer model is carried out as follows.

(a) The limit of the field of view is added by superimposing a circle of 20° subtense centred on the tunnel portal at a height of 1.5 m from the road surface as shown in figure 9.

(b) The 20° field of view is divided into areas (see figure 10) and each area identified with a reference number or letter. A luminance value L is assigned to each area A using a measured value taken at the site or a typical value from table 6.

c) A schedule of the areas is now made up as indicated in table 7. The summation of A and AL gives the total area and the total luminance respectively; the average luminance, i.e. L_{20}, can then be found by division.

d) The effect of varying the luminance of some of the objects in the field of view can be studied. This facility can be useful when determining the finish to be used for the portal or the retaining walls. It may be found that the finish could have a significant effect on the access zone luminance. (see **17.6**).

e) The grid method can be used to investigate the adaptation as the field of view changes when approaching the tunnel. In this way the adaptation point can be found for calculating the threshold zone.

Finally it should be noted that the grid method is an approximation and the accuracy is dependent on the particular luminances used in the calculation. Table 6 gives a guide to typical values occurring in Europe. Site measurements should be taken where possible (see appendix B), particularly when the orientation of the tunnel will produce different results for each approach.

Table 6. Typical luminance values

Background	**Luminance L** cd/m^2
sky (clear)	8 000
sky (hazy, bright) occurs when facing in southerly direction	20 000
grass	2 000
hill (rock, scree)	3 500
earth/sand	3 500
tree	1 000
portal (dark)	1 000
wall (dark)	1 000
wall (light)	6 000
road (asphalt)	4 000
road (asphalt) in sun when facing in southerly direction	6 000
road (concrete)	8 000
house (brick)	3 500

NOTE. These values are for midsummer in full sun with horizontal illuminance approximately 100 000 lx. Where a surface (other than the sky) is in shadow at the time L_{20} is maximum then the above values should be multiplied by 0.25.

Appendix D. Example of tunnel lighting design

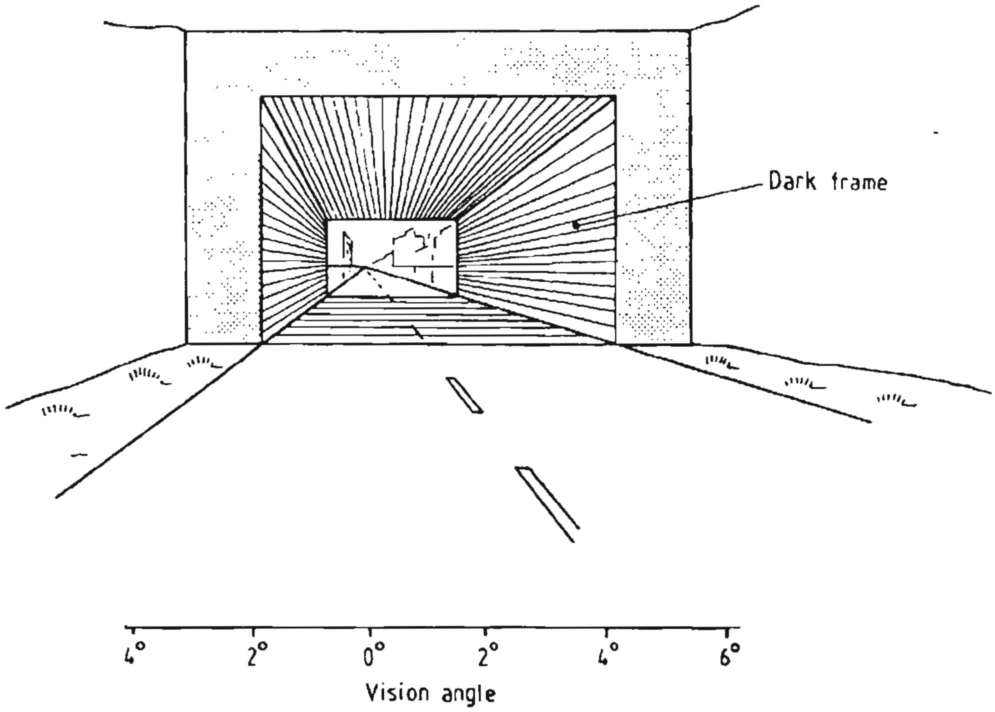
D.1 General

The following example shows how to apply the recommendations when designing a tunnel lighting system. The method used will be found to be satisfactory for a first approximation; a more detailed study can be carried out by using a computer and photometric data from an actual luminaire.

Table 7. Example of calculation for determining access zone luminance L_{20}

Area	**Background**	**Area (A)** (arbitrary units)	L cd/m^2	AL
a	sky (clear)	2 600	8 000	20 800 000
b	dark wall	1 150	1 000	1 150 000
c	dark wall over portal	300	1 000	300 000
d	road (asphalt) in sun	3 300	4 000	13 200 000
e	road in shadow	80	1 000	80 000
f	dark wall in shadow	128	250	32 000
g	house (brick) in shadow	130	875	114 000
h	trees	90	1 000	90 000
i	sandy medians	800	3 500	2 800 000
j	tunnel interior	922	–	–
Total		9 500		38 566 000

Average luminance $L_{20} = AL/A = 4060$ cd/m^2



Tunnel dimensions:

100 m long
7 m wide
5 m high

Viewed from 70 m with the driver's eye height 1.5 m above the road surface.

Figure 7. View of a short tunnel showing the dark frame

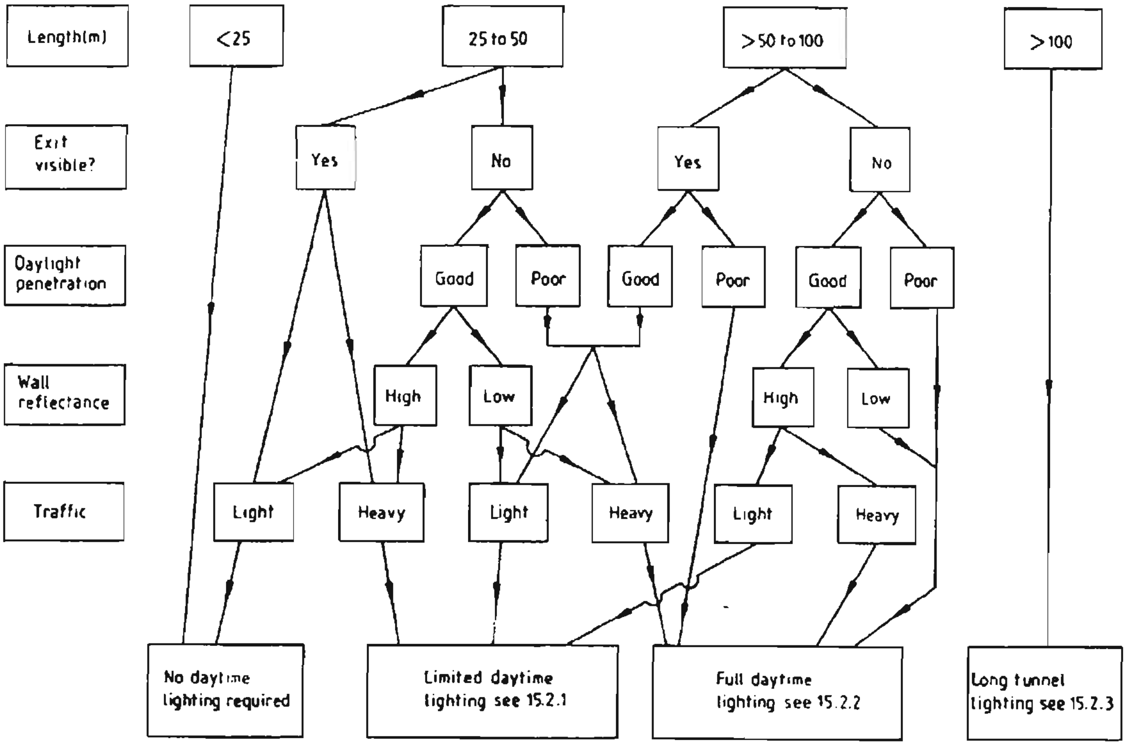


Figure 8. Daytime lighting of short tunnels

Publication(s) referred to

BS 5225	Photometric data for luminaires Part 1 Photometric measurements
BS 5420	Specification for degrees of protection of enclosures of switchgear and controlgear for voltages up to and including 1000 V a.c. and 1200 V d.c
BS 5489	Road lighting Part 1 Guide to the general principles Part 2 Lighting for traffic routes
BS 6100	Glossary of building and civil engineering terms Subsection 2.4.1 Highway engineering

Department of Transport Standard TD 9/81, Road layout and geometry – Highway link design, August 1981 and Amendment No. 1 January 1985

PIARC 1979/83/87, PIARC Road Tunnels Technical Committee Reports at Vienna (1979), Sydney (1983) and Brussels (1987)

CIE Publication No. 61 'Tunnel Entrance Lighting' (1984)

Walthert, R. 'Tunnel lighting systems' International Lighting Review, 4, 112 (1977)

Issue 2, May 1996

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Contract requirements

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the responsible technical committee, the identity of which can be found on the inside front cover. Tel: 0181 996 9000; Fax: 0181 996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services, Sales Department at Chiswick: Tel: 0181 996 7000; Fax: 0181 996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library, the Standardline Database, the BSI Information Technology Service (BITS) and its Technical Help to Exporters Service. Contact the Information Department at Chiswick: Tel: 0181 996 7111; Fax: 0181 996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Customer Services, Membership at Chiswick: Tel: 0181 996 7002; Fax: 0181 996 7001.

Copyright

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

If permission is granted, the terms may include royalty payments or a licensing agreement. Details and advice can be obtained from the Copyright Manager, BSI, 389 Chiswick High Road, London W4 4AL.

BSI
389 Chiswick High Road
London
W4 4AL

ISBN 0 580 20900 8

LGL/23